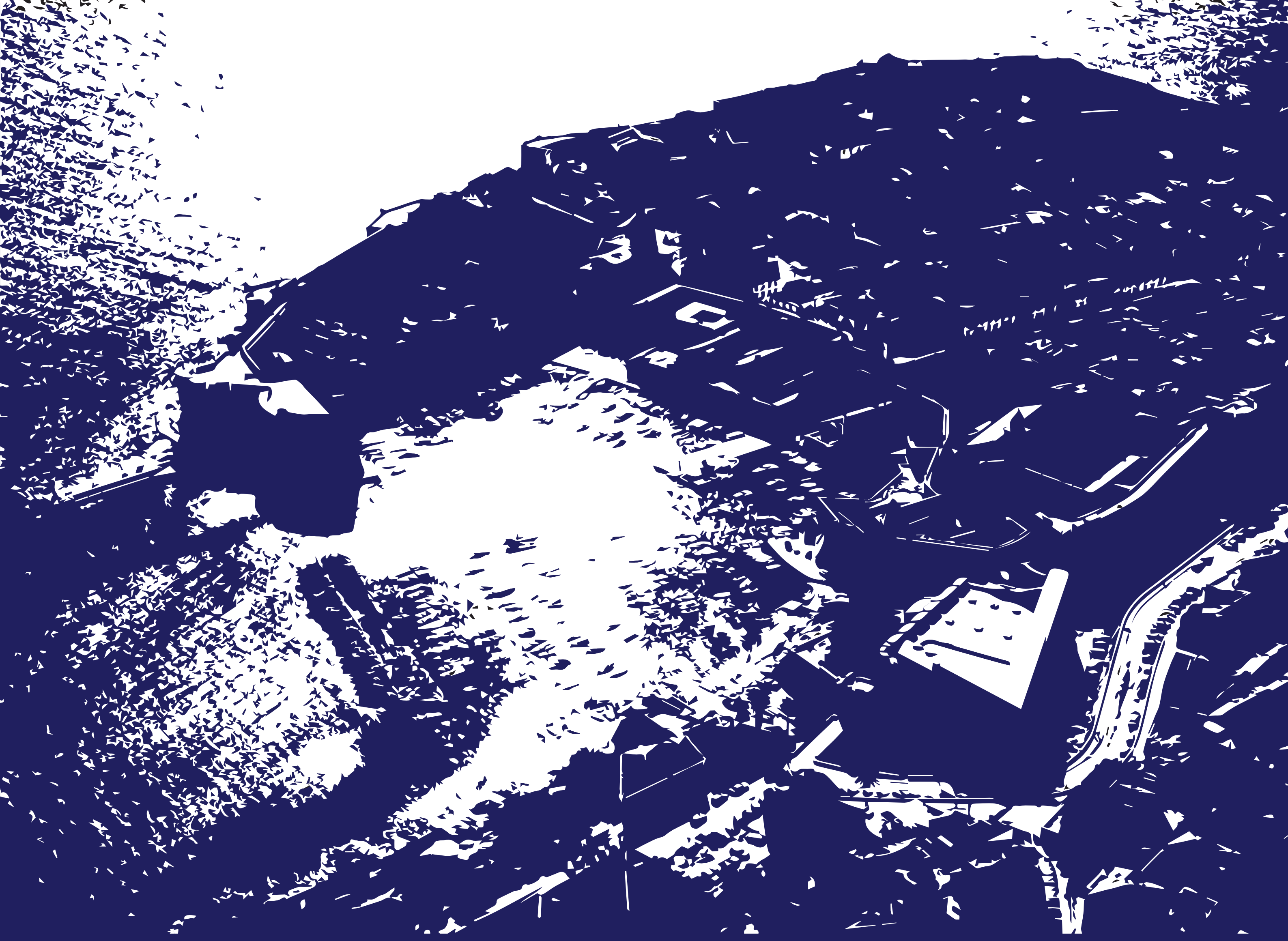

NAŠE MORE 2019

1st International Conference of Maritime Science & Technology

Dubrovnik, 17 - 18 October, 2019

University of Dubrovnik
Maritime Department

University of Rijeka
Faculty of Maritime Studies

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CONTENT

GRAPH-ANALYTICAL METHOD FOR ASSESSING THE STATE OF THE OBJECT BEING DIAGNOSED

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Summary

The author proposes a method for diagnosing a technical object, when the data set for assessing its state exceeds the multiple threshold of its characteristics is known to the experts about the state of the object under study, even at theoretical infinity of the basic parameters. The method is based on graph-analytical representations.

Keywords: diagnostics, control, management, graph, indicator, parameter, factor

1. INTRODUCTION

Scientific and technical progress at the end of the 20th century led to implementation in practice shipbuilding and ship repair new methods of the organization of production taking into account progress in nanotechnologies. This process became noticeable also in forming of ship-building sets: power stations, the completing materials and products, the navigation systems, details of cases and room finishing, ship loading and unloading facilities.

This progress requires an increase in the level of operational and technical indicators of the quality of all ship elements. In this regard, the estimated service life of vessels and their elements also increases.

According to the operating conditions, the safety of navigation and the warranty period, the terms of technical inspection are established. It is clear that elements of ships and ship equipment wear out unevenly. On the other hand, technical progress constantly requires the replacement of equipment and the renovation of any design, even between established periods of technical inspections. Depreciation of equipment often do not coincide with the established deadlines for inspections. Under these conditions, there is a constant increase in the number of controlled parameters on the state of the object (vessel) and its elements.

The consequence of this situation was a sharp increase in the number of controlled indicators of the quality of any element of the ship equipment. Here, the diagnostics of the object encounters the "curse of dimension": any combination of the initial indicators causes an avalanche-like (multiply-connected) combination of unimportant indicators with basic ones. Then the conclusion about the significance of a particular indicator is possible only at the expert level [6].

Here it is important to notice, that expert conclusions about the main and insignificant indicators are conditional. For example, at elevated (lowered) external temperatures, the viscosity criterion for the oil of an internal combustion engine is important, and under normal conditions it can be neglected. Another example: the voltage fluctuations in the lighting network are of little significance, and in navigation automation systems are very important and require special stabilization equipment. Analysis of existing methods for controlling objects by a finite set of indicators showed their low efficiency [4].

The identification of new indicators and characteristics determines the need for additional tools to improve the quality of the integrated measurement of their parameters. Traditional means of algorithmic modeling of such processes (cyclic and nested cycles) collide with the dimension of infinity and cannot solve this problem. To this we add that almost all parameter estimates are probabilistic (statistical) in nature. They require constant correction.

So the problem arises: to develop a methodology for assessing the state of the object being diagnosed for a set of its final factors in the conditions of the revealed set of its main (basic) and current (little significant) indicators.

2. FORMULATION OF THE PROBLEM

The analysis of any product begins with the identification of many parameters by which it is necessary to assess its condition. To give such an estimate on an infinite set of parameters for all elements of the vessel is unrealistic. This process depends on the degree of knowledge of the parameters, technical, theoretical and statistical calculations, measurements and tools for determining the real assessment of each of them. The degree of uncertainty of measurements and parameter calculations is determined by the tolerances (fluctuations) that the researcher may take for a possible error (Δxijf). Usually choose the group of the most significant parameters with their tolerances: 5-7% of the measured value. They are taken as criteria for assessing the state of the object (indicator). The rest are interpreted as limitations of the object model being formed. Such an approach leads to the fact that the violation of any restriction is considered as a fact of inoperability of the object (marriage, unreliability, low quality, etc.). According to the rules of the Theory of Systems, such an object (element, product) is considered ineffective [7,8,10]. There is no sense to search the Pareto set on this path, since it is itself a subset of effective solutions for xij (Fig. 1).

Therefore, the optimum quality of an object can only be found by groups of criteria characteristics [1].

The remaining characteristics of the object determine the indicators that record the fact of inoperability, unreliability, deviation of the monitored value from the given one. This causes rejection of this product. Here, a decomposition of the structure of the object (vessel) and the elementarization of products by controlled parameters at each level (factor) are necessary.

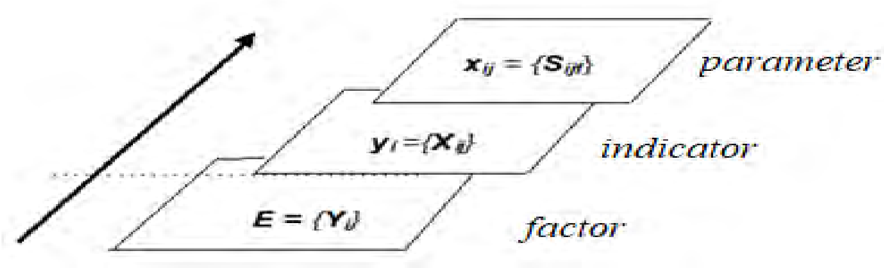


Figure 1 Scheme of factor analysis of the state of the object

At the initial level of diagnostics, factors (E) determining the general condition of the object (vessel) are considered. Priority fact: the purpose of the operation of the ship: gas (explosion), movement in ice (special building), sediment (navigation at shallow depths), etc. The combination of such factors is { Yi}. Entering specific factors into the model or their combination {Yi} defines the Maritime Register. At the same time, all selected factors are considered equally important. This solution distinguishes the logical-reflexive method from other methods, including logical-probabilistic. It allows you to quickly exclude (include) additional factors in forecasting, avoiding probabilistic estimates.

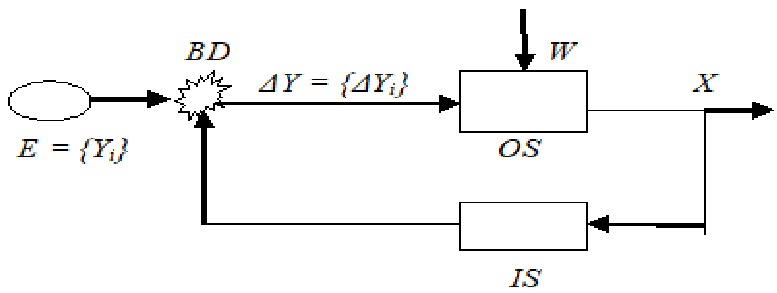
The next stage of decomposition refers to the functional complexes (X): power plant, deck equipment, navigation systems, propulsion systems, etc. Finally, the parameters of specific devices, elements, blocks (S) are diagnosed. At each level, the procedure of replacement, renovation, regulation is acceptable, if the product does not meet the specified specifications. The specified technical conditions (dimensions, characteristics, level of wear) are accepted as a standard of either a single product or a complex or structure as a whole. It is important to note here. that the technology of selecting the characteristics of elements and the justification of their values for the Databases at each level is similar. In this regard, we will dwell on the initial level of the assessment of the state of the object under study - the organization of monitoring the parameters of individual products and parts that make up the ship's complexes and structures.

An effective way to solve such diagnostic tasks can be considered a semantic network, when for a pair of vertices i and j an arc of the value k (i, j) ∈ [0,1] corresponds. This value determines the degree of belonging of this pair to a fuzzy relation. In reality, this process characterizes the incomplete knowledge of the subject, who is aware of the causal relationship i - j, but cannot explain the intermediate links of reasoning. It is intuitively clear that there are many similar pairs between i and j, but the researcher does not have the appropriate knowledge and data to identify them [2]. In addition, the semantic network is simplified linear-flat (two-dimensional) character. In such cases, the formal model takes the form

$$F = < S, Mr > \tag{1}$$

where S is the revealed set of properties of an object with specific values, and Mr is a fuzzy relationship "cause-effect" on the set S. The semantics is that if zi = (qi, vi), zj = (qj, vj), (qi qj) ∈ S, i ≠ j, when vi, vj are the values of the qi qj properties, then for each pair (zi zj) there corresponds a number to (zi, zj) [0,1], which determines the degree to which the pair belongs to the non-equal relation.

At the same time, abandoning a rigorous mathematical solution for the multiparameter estimation of the state of an object, it is logical to introduce into the model some system of conditional codes. Then each known or potentially acceptable parameter is considered equivalent in the representation of the object state indicators [5]. The quality of the state of the object will be determined by the final set of its indicators in accordance with a reasonable standard. This coding should be laid into the model of the identified groups of parameters xij as a certain set of indicators Yi. Therefore, it is possible to consider as a reference such a state of an object (product), when all its factors E are identified and uniquely correspond to the system of given indicators yi. The basis of the above conclusion is based on reasoning based on the modified N.Wieners scheme (Fig.2).



OS - object of management
E - the standard (model) of the control object
BD - block decision on the state of the object
IS - information and measurement system
W - external environmental impacts on the object

Figure 2 Modified scheme by N. Wiener

Indeed, if some system (OS) is taken as the object of diagnostics, it is not difficult to determine the standard of its state E at each moment of time or at a certain interval of its operation.

In real management processes and for such a benchmark, you can take a set of predetermined or calculated factors E = {Yi} (i = 1, I). They have fixed values: I is the number of valid factors assessing the state of the object [3]. Prediction makes no sense to give a probability estimate for these values. Any deviation from the reference (+ Δyi, -Δyi) is an error, reducing the quality of the element in relation to the standard. It should be taken into account as a calculated value, obtained on the basis of estimates of X, S. It takes the absolute value of y = | y - Δyi |. To do this, one should define a group of indicators yi (yi = {Xij}, j = 1, J), which form the given object factor and give it an estimate for each of the indicators yi.

The manifestation of any aggregate ΔY, obtained according to the IS data, is interpreted as a violation of condition E and requires an appropriate BD reaction in assessing the OS state. Therefore, it is necessary to enter a finite set of parameter groups Sijf into the estimate of each Xij indicator, when xij = {Sijf} with f = 1, F, where F is the number of initial parameters for evaluating the state of the object (Database).

At this level, a specific parameter is considered as a measurement value (calculation). It is estimated by the actual output indicators of the operation of the object at the moment or for a specified period of time (monitoring interval, forecast period, object lifetime, etc.). Here you need to specify that the indicators on the state of the object should be justified by measuring parameters, sensor readings or documented information with numerical values.

Let us take as a measure of the quality of an object the result of a comparison of procedures for the consistent assessment of fixed groups of parameters, indicators and factors given with their benchmarks set by the customer (user).

3. GRAPH-ANALYTICAL METHOD FOR DIAGNOSING AN OBJECT

From the standpoint of System Theory, a set of factors free from errors (deviations) of their indicators and parameters can be taken as the standard of the state of the object being diagnosed. They underwent control procedures, i.e. ∑ΔYi = 0. The statement is valid at W = 0 (Fig.2). Here the semantic problem immediately arises. The elements that make up the system being analyzed (production, process, control, etc.) almost always have a different physical nature, measurement characteristics, methods of determination and control. This is clearly manifested even in the elementary systems of mass production of microcircuits, hardware, fasteners, etc. Consequently, the scheme for assessing factors indicator - parameter according to the principle of tolerances, probability conditions, statistical calculations is approximate. At the same time, the methods of multivariate analysis are too clumsy and difficult for simple objects that produce low-value products. But already at the next step of assessing the state of an object, the task becomes more complicated: each of the parameters can retain its constant value, but only within a particular task. Switching to another production option or changing a task (equipment changeover, tool change), the parameter, as a rule, changes its value. For example, the cleanliness of the surface in the processing of the shaft for instrumentation is the main parameter, and in the production of gearboxes is secondary.

It is clear that the measurement error is present in both versions of the given example and cannot be zero (Δ ≠ 0). Therefore, it is always taken into account, as a negative error in the evaluation of both this indicator and the parameter (factor). It is not difficult to conclude that the assessment of the state of any object or technological process is a ternary system of sequential operations, which can be schematically represented as a linear algorithm (Fig. 1).

However, to assert that the totality of the indicators Y is the standard E in such an entrée is not fair. Each Yi characterizes a specific group Yi (i = 1, I). These groups are varied on the scale of measurements of physical, economic, informational and other factors. For the most effective decision result in BD about the state of the object, it is necessary to change the coding system of the initial data on the factors and bring them to the same logic of the parametric representation. In this interpretation, we consider a two-step procedure for the implementation of this proposal:

1. The logic of system analysis dictates the condition of the multifactorial nature of objects and phenomena. Then the researcher is in a very difficult position. It is unrealistic to take into account all possible factors for evaluating an object because it is impossible to form a multifactorial Database because of the limited amount of knowledge, the fleet of monitoring and measuring equipment, the lack of methods and means of calculation

(**S**$\in$X, X$\in$Y, Y$\in$E). In addition, factors may be of different nature and contradictory: safety, economy, ecology, etc. You must enter a relative measure for each of the many known for this object values S, X, Y on a conventional scale of measurement (0 ≤ E ≤ 1),

Suppose that the reference value of each parameter Sijf in the sequence $s_{ij1}, s_{ij2}, s_{ij3}, s_{ij1}, \ldots s_{ijF}$ (f = 1,F). is known (calculated, established). If the values of the parameters S are arranged linearly along the time axis of the abscissas, and the values of the indices X are on the y-axis, they will merge into an unordered straight line. Their comparability at the level of factors E will be random. The flat-pair arrangement of the parameters X gives an adequate estimate only for a given pair of indicators and does not solve the problem of assessing the state of an object through the characteristics of groups using factor E as a whole [9,10].

We assume that in the assessment of the quality of an object, each identified parameter is equal to the others when evaluating the indicator j. Then you can go from the absolute scale of their presentation to the relative (single) form:

$$s_{ijf} \longrightarrow 1{,}0$$
$$s''_{ijf} \longrightarrow z \qquad (2)$$

Having solved the traditional equation of transition to a relative scale, we obtain the value of each parameter on a unit scale of measurement:

$$z_{igf} = s^{*}_{igf} \cdot 1.0 / s_{igf} \qquad (3)$$

2. Present the results in tabular form. We will take it for the Database to assess the state of the object by parametric analysis (Table 1). The data in Table 1 implies the finiteness of the number of parameters Sijf in each group of indicators Xij.

Table 1 Database for assessing the state of an object by parameters

№	Parameter (sijf)	Code parameter	Absolute value	Relative value
1	2	3	4	5
1	parameter definition s_1	*ij1*	s_{ij1}	z_{ij1}
2	parameter definition s_2	*ij2*	s_{ij2}	z_{ij2}
3	parameter definition s_3	*ij3*	s_{ij3}	z_{ij3}
…	…………………………….	…………...	…..………..	………………
f	parameter definition s_f	*ijf*	s_{ijf}	z_{ijf}

It should be noted that in the proposed model any deviation of the parameter Xij (± ΔXij) indicates a decrease in the quality of the indicator and the factor of the state of the object as a whole [7]. Then the model of the state of the object can be represented by a set of values of groups of parameters and indicators that make up the system for assessing the decision on a finite set of factors [3]. For example, if a specific indicator is estimated by 8 parameters, then we distribute them evenly around the circle (450). The length of each vector corresponds to the value of the parameter on the relative (single) scale of measurement (Fig. 3). Consequently:

$$r = 1.0;\ D = 2.0;\ L = 2\pi;\ P = \pi \qquad (4)$$

It can be argued:

1. The more an element (product, object) is studied, the more vectors in the unit circle.
2. The length of each vector is determined by the current value of the parameter.

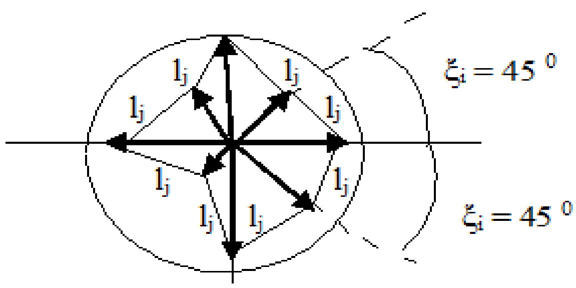


Figure 3 An example of a graph-analytical model for assessing the state of an object.

3. The larger the vector, the closer the object in the Sijf parameter to the reference estimate (Sijf = 1).

Arguing in a similar way, we establish that, at xij ∞, the quality of the state of an element of an object can theoretically be established with a probability P = 1.0 both in terms of the totality of parameters and in terms of the parameters yi and factor E derived from it. This solution is also effective for modeling the state of an object in case of a sudden failure (full or partial) of one of its elements. It is enough to either exclude the vector - the indicator lj of this element, or reduce this vector by the corresponding value (Fig. 3).

To assess the state of the object as a whole, it is sufficient to correlate the theoretical length of the unit circle L0 with the length of the broken line connecting the vertices of the vectors of the real parameter estimates (Lf):

$$L^0 = \pi D = 6.28,$$
$$L_f = \sum I_{igf}\,(f = 1, F) \qquad (5)$$

Reasoning in this way, we get a gyromat (Fig. 4).

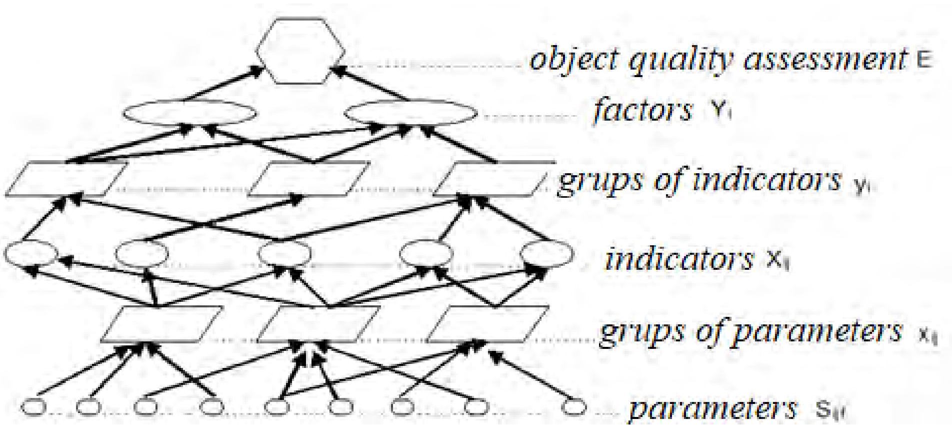


Figure 4 Giromat state of the control object

Based on the logic of the gyromat, an object is diagnosed on a single scale both as a whole and at each of its levels:

$L^0 = 6{,}28$ is the absolute quality standard of the object under study.

$L^0 - L_{ij} = \Delta L_{ij}$ is a parametric measure of the state of the object under study.

$L^0 - L_i = \Delta L_i$ is an exponential measure of the state of the object under study.

$L^0 - L_E = \Delta L_E$ is a factorial measure of the state of the object under study.

4. CONCLUSION

Thus, for each object factor, taking into account its originality (specificity), it is possible to give a well-founded assessment of the object or product by the set of its identified and calculated parameters (indicators) using the graph-matrix method. At the same time, acting in a similar way, when it is possible to substantiate the measures and the nature of the various factors of the state of the object, it is quite acceptable to conduct its multifactor analysis.

REFERENCES

[1] Aref'yev I.B., Korovyakovskiy Ye.K. Printsip raspoznavaniya problemnykh situatsiy na baze integral'nykhkharaktepistik // Gibridnyye i senergeticheskiye intellektual'nyye sistem. 2016. Kaliningrad, Izd-vo BFUim. Kanta. C. 206-217.

[2] Aref'yev I.B. Logiko-refleksivnoye predstavleniye modeley drevovidnykh struktur. // Sistemnyy analiz v proyektirovanii i upravleni. 2014. SPb, Izd-vo SPGTU. C. 56-60.

[3] Ariefiew I. Logikal and reflective modelling of the processes of making and supporting decisions to management. // Sistemnyy analiz v proyektirovanii i upravleni. 2019. SPb, Izd-vo SPGTU. p. 194-201.

[4] Aref'yev I.B. Elementy metoda logiko-refleksivnogo modelirovaniya. Iz-vo „LAMBERT akademik publishing", Riga. 2019. 68 p.

[5] Karpov A.V. Psikhologiya refleksivnykh mekhanizmov deyatel'nosti. // M. Izd-vo «IP RAN», 2004.- 31 s.

[6] Kant E. Kritika chistogo razuma. M: Mysl'. Soch. tom 3. 1964

[7] Chebyshov P.L. Polnoye sobraniye sochineniy.— Izd-vo AN SSSR, 1948.— T.III.— S. 404

[8] Mundzhishvili T., Logiko-veroyatnostnaya model' otsenki finansovogo sostoyaniya predpriyatiya, Trudy Tbilisskogo Universiteta, prikladnaya matematika i komp'yuternyye nauki, #364 (24), str. 216-229, Tb., 2005

[9] Polenin V.I., Mozaev A.C., Gladkova I.A. Obszij logiko-verojatnostnyj metod modelirovania sloznyh system. monograf. Germania. Palmarium Akademik rublishing. 2015. 688 c.

[10] Mathias Niepert and Guy Van den Broeck. Tractability through Exchangeability: A New Perspective on Efficient Probabilistic Inference. Proc. AAAI, 2014, pp. 2467-2475.

INTEGRAL TRAFFIC MODEL OF THE DUBROVNIK-NERETVA COUNTY

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Summary

As a heterogeneous area in geographic terms, the Dubrovnik-Neretva County is proportionally non-functional in traffic terms. Various parts of the County are not well connected, which is a result of political, economic, historical, cultural and other factors. It is the requirement of utmost importance to provide more rational logistic connections between the starting and destination points in local as well as in far distance traffic. The focus of the analysis of traffic and technological solutions to this multilayer issue is the City of Dubrovnik with its numerous specific features that make it significantly different from other Adriatic towns. It is the main destination for maritime cruises, which, due to the large number of guests, represent the main problem in the functioning of local public and individual transport in the peak season. An expressly growing trend is present in the passenger air transport on the track of the reconstruction of the airport of Ćilipi. The expansion of road traffic in the narrow urban area has initiated the introduction of alternative traffic and technological solutions. This paper brings an algorithmic presentation of the research and methodology dealing with optimization of the whole traffic system. Any existing as well as future infrastructure construction separate projects concerning all transport branches should be put before the introduction of an integral transport model. Specifically, this refers to the city of Dubrovnik as the main hub in the matrix of transport and logistics flows of all types of transport substrates.

Keywords: traffic infrastructure, maritime cruises, inland network, air transport, integral traffic model.

1. INTRODUCTION

The Dubrovnik-Neretva County is the southernmost county in the Republic of Croatia and is territorially organized in 22 local government units and 5 municipalities (Dubrovnik, Korčula, Ploče, Metković and Opuzen) and 17 municipalities (Blato, Dubrovačko primorje, Janjina, Konavle, Norina, Lastovo, Lumbarda, Mljet, Orebić, Pojezerje, Slivno, Smokvica, Ston, Trpanj, Vela Luka, Zažablje and Župa dubrovačka). The County Center is located in the City of Dubrovnik. The area of the County consists of two basic functional and topographic units: the area of Donja Neretva with a gravitating coastal area and a relatively narrow longitudinal coastal area with a series of nearby and near islands (the most important ones being Korcula, Mljet, Lastovo and the Elaphite Islands group). The area is interrupted by the state border with Bosnia and Herzegovina and only in the area of Donja Neretva valley has a natural connection with the interior and the connection to the north or towards the Pannonian part of Croatia Historically the determinant is the very weak land connection of the Dubrovnik area both within the County and the rest of Croatia, and it can be said freely with the rest of Europe, since Croatia since 01.07.2013. a full member of the European Union. Just taking the policy of developing the Dubrovnik political scene as a dominant factor in achieving a consistent spatial-traffic strategy throughout the county, it tries to find optimal solutions using all available instruments.

2. TRAFFIC RELATIONSHIP OF SOUTH DALMATIA IN FUNCTION OF TOURIST TRAFFIC

Due to its geographic position, southern Dalmatia is the most difficult region available in Croatia. Due to the untended part of the A-1 motorway and the lack of railway links, the safest thing is to get to this work by plane, ferry or bus. In South Dalmatia, Dubrovnik Airport is located 22 kilometers away from the city center with direct flights to Zagreb, Split, Osijek, Osijek, etc. The old Adriatic highway, ie the state road D-8, is considered a historical category and has undoubtedly played a crucial role in the development of the southern part of Croatia. Dubrovnik is connected with the sea by regular ferry lines with Rijeka, Split and the island of Hvar, and other destinations in the gravitational waterway area, ie from the ferry port it connects the international ferry line to Bari in Italy. In South Dalmatia, the train can only be reached from Bosnia and Herzegovina via Mostar and Ploče from Sarajevo. Plates are connected with direct rail lines with Metković, Sarajevo and Zagreb. All relevant tourist destinations are connected with the bus lines that drive regularly and disperse to the rest of Croatia.

The Dubrovnik area and its county center the city is extremely tourist-oriented and there is a steady growth of tourist traffic. Most of the tourist traffic is realized in the summer months. For example, in the period june to september, that is, in the third of the year, more than two thirds of tourist arrivals are realized. The pronounced seasonality that heavily influences the demand for transport results in a high unequal coefficient in the transport sector, which poses an extremely demanding task to the subjects of transport offers and to those who manage and decide on traffic. Of course, all the mentioned seasonal activities are affected by traffic demand. But it should not be forgotten that the demand for transport is already overloaded with the daily, current domestic needs, that is, the regular requirements imposed on the public sector, transport for own needs and individual traffic.

Table 1 Statistical Indicators of the Dubrovnik-Neretva County

Dubrovnik - Neretva County	Land part	Sea part	Total
Area of County:	1782,49km2	7 489,88km2	9 272,37km2
Length of the state border:	164,29km2	253,42km2	417,71km2
Longitude of the county border:	25,29km2	118,66km2	143,95km2
Total border length:	189,58km2	372,08km2	561,66km2
Relative percentage of surface relative to RH.	3,15%	22,56%	10,32%
Republic of Croatia	Land part	Sea part	Total
Area:	56 609,59km2	33 200,00km2	89 809,59km2
Length of the state border:	950 km	2 978 km	2 028 km

Source: Prepared by authors according to data from the Croatian Bureau of Statistics offical website

All indications show that traffic demand focused on the area of Dubrovnik is increasing, so it demands that problem-solving be approached: systematically, long-term, rational and scientifically based.

Hypothetical, solutions should be sought in the following:

a) building a new traffic infrastructure
b) reconstruction of existing traffic facilities,
c) the reallocation of transport demand,
d) relative reduction of traffic demand,
e) traffic constraints

Each of these solutions or their combination has the advantages and disadvantages, and its price. Appropriate solutions can be obtained through thorough and continuous research with thorough preparation, fundamental research, and the application of relevant scientific methods multicriteria analysis.

3. INFRASTRUCTURE OF PROMOTIONAL SUBSIDIES

3.1. Road transport subsystem

In planning road network development, there are still some doubts about how to conduct major road corridors in this area. The first variant, suggested by the Strategy of physical planning of the Republic of Croatia, is the Adriatic road that passes through the territory of Croatia (with a break in Neum). The second variant is the Adriatic Ionian auto-road that should connect the county to the west and east, but the route to the Neretva area leaves the territory of the Republic of Croatia. The Spatial-Traffic Study of the Road Network of the Dubrovnik-Neretva County was developed for the purpose of the Spatial Plan of the County, according to which the main road directions are planned. Based on this study, a corridor will be selected for the management of the Adriatic Ionian Autostrada and the route of the TEM Autostrada (Trans-European Highway of Central Europe - Slavonia - BiH - Ploče) in the international transport corridor Vc. Additionally, this Study also defines the Ploče - Dubrovnik - Debeli Brijeg highway route, which should function within the county connection in combination with the Adriatic Ionian Autostrada, as it is leaving the territory of the Republic of Croatia in the Neretva Valley. Existing road D-8 (Adriatic road) and D-414 (Pelješac Bridge) will be building, on the state road D-118 Vela Luka - Korčula is planned a ring road to Zrnovo settlement and the Cara-Smokvica ring road. The Peljesac Bridge, therefore, has a key role in the fast road project to Dubrovnik, and is the pivot element in the matrix of road linking between Dubrovnik and the Dubrovnik Neretva County with the rest of the country. It represents the beginning of a fast road and is vital to such a road. By extending the road route through Pelješac, building the bridge, the connection of the whole country is finally realized, thus the traffic isolation of Dubrovnik and the whole of the County becomes a past. With the arrival of the road to Peljesac peninsula, the opportunity is opened for connecting Korcula, Lastovo and Mljet with the rest of the country, coming to Ston and returning to the coast of the Republic of Croatia. The option is to go through Ston and next to the solano in Ston and return to the main shore by the bridge on a steep slope along the Ston Channel. The county authorities are demanding that the road does not pass through Ston, or along the Ston Channel, but through it. The solution is to penetrate tunnels of about 600 meters through Polakovica and bridge construction over the canal. The road at the crossing of Ston to the land area goes through the coast, and is conditioned by a narrow belt between the village and the border with the neighboring state. It was conceived in such a way as to forbid the villages and did not cross them, and the construction of the road by this route would require some smaller tunnels and viaducts. The road continues in the direction of the village of Osojnik, where there is a junction, and on the very tip of the Dubrovnik River turns to the left and follows the slope. Crossing the river is actually crossing the river over the slopes, as it minimizes the environment. Such a solution is much more convenient and technically feasible. For example, tunnel drilling is impossible because of the proximity of the source, and because of the already existing power plant. The downhill slope is the best aesthetic, economic and technical solution. After crossing the slope of the road towards Čajkovic, and towards Parež, a 800-meter tunnel extends towards Župa Dubrovačka. Exiting the Župa, the Dubrovnik road goes uninterruptedly to Čilipi, where the airport is bypassed, and a border crossing at Debel Brijeg is gradually coming to an end. Note, the construction of the Peljesac Bridge in its entirety changes the picture of the complete road transport system and maximizes the valorisation of the geopolitical position of the Dubrovnik-Neretva County.

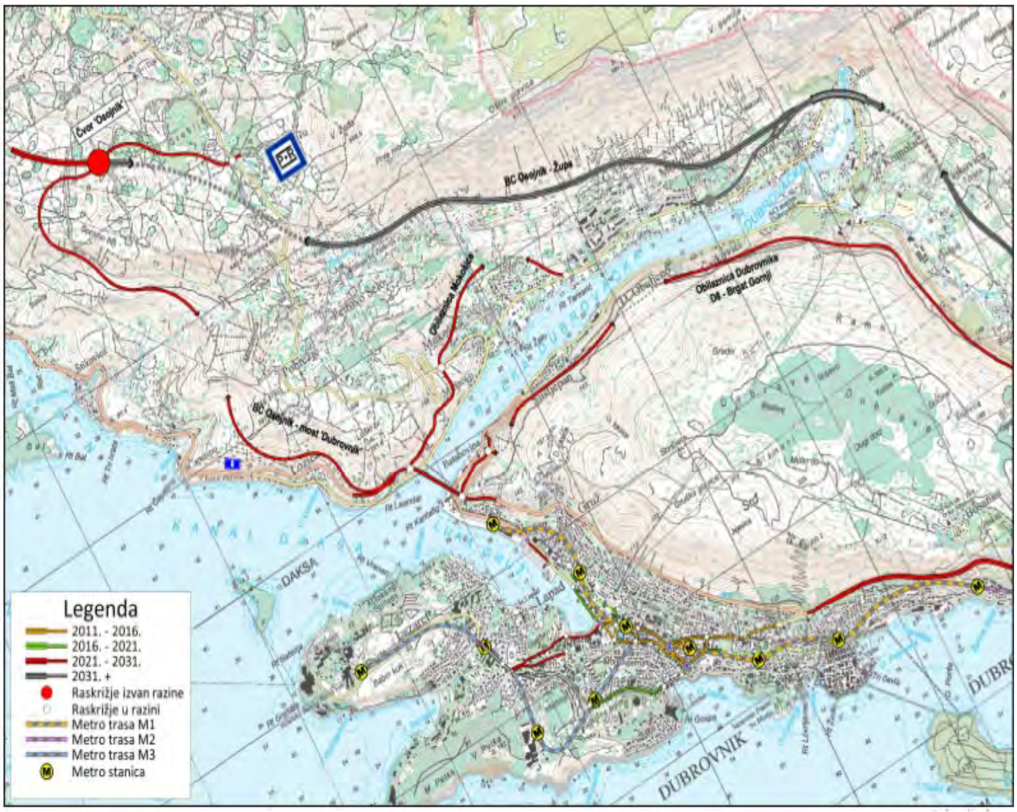

Figure 1 Overview of the improvement of the road network in the wider area of Dubrovnik from 2021 to 2031.

The city of Dubrovnik is connected with the rest of Croatia by state road D8, in the north by the bridge "Dubrovnik" and by the south road D8 towards Dubac. From intersection D8 to D233 GP Gornji Brgat (border of BiH) - Dubac Dubrovnik connects to Bosnia and Herzegovina. In the future analyzed through 18 network scenarios for 4 time slots (2011, 2016, 2021 and 2031), Dubrovnik will continue to be connected to the "Dubrovnik" bridge in the northwest and to the south via the Dubac intersection. In the north of Dubrovnik, a fast road will be connected to the national highway system at Osojnik. In the south, the fast road system Župa - Plat – Čilipi, Dubrovnik will be connected to the node of Župa, which is geographically located north of Donji Brgat. The fast road Doli - Dubrovnik - Debeli Brijeg represents a state investment of higher priority. The external road transport system of the City of Dubrovnik evolves slowly in the absence of balanced political decisions and the real need for increased transport capacity.

3.2. Maritime traffic subsystem

Regarding maritime traffic, the ports of Ploče and Gruž are perceived as ports of international significance, and six other ports of county and 74 local importance represent significant infrastructure value. In the focus of research, the City of Dubrovnik should be placed, which is the starting point and the end point of almost all itineraries in the maritime travel matrix. A relatively well-known idea of potential utilization of maritime transport resources is the option of transporting tourists from cruisers unloaded in Gruž to the Old city core vessels. Instead of entering the buses, guests would board the fast boats that would drive them to the destination. Port of Gruž already owns a built row suitable for unloading and boarding the entire length of its passengers. It would be ideal to board / unload guests on a new part of the waterfront, under the Dubrovnik bridge, which is intended for domestic traffic. This would reduce the number of visitors per port to a minimum. In the old port the situation is not so good. The old city port is already overloaded because all the traffic on local routes (according to Cavtat, excursion boats) as well as the transfer of passengers from passenger ships that are anchored to the Lokrum anchorage, takes place inside. Therefore, it would be necessary to build a floating point of sufficient size to accommodate at least two boats simultaneously and to withstand the total number of passengers staying there. At the same time, upon the realization of the pontoon, forbid the "tender" of boats from the boats located on the anchorage "Lokrum" entry into the old port, they are already diverted to the pontoon for the loading / unloading of passengers from the mother ships. The ideal position for a pontoon accommodation would be beneath the "Lazaret", where there is already a hiking trail leading to the east entrance to the city (Ploče), which should be adapted to accommodate the number of people who could move. This would reduce the number of passengers in the old city harbor, and tourists are offered a new, wider city experience. The position of the pontoon would be secured with concrete anchors lowered to the sea bottom and connected chains for the pontoon itself. When the tourist season passes, ie when winter time occurs, that same point would be separated from the anchor and placed in a secure location (Rijeka Dubrovačka-Kaboga) or saved to "dry" in order to protect it from adverse weather conditions during winter period. With regard to economy, it would be necessary to have the capacity of the vessel and the price of the charter to justify the total resources spent on transport (boat purchase, maintenance costs, fuel and employee benefits) through a long-term sustainable plan. The cruise line should be aligned with the arrivals and departures of passenger ships. The size of the water park would be determined after one year of exploitation after analyzing all the transport-economic parameters of this project. Starting with the development of the Dubrovnik passenger port development project, which is primarily concerned with the creation of prerequisites for the reception of ships on cruises, the Port Authoritiy of Dubrovnik has begun a comprehensive venture of creating a modern passenger port with multifunctional facilities intended not only for passengers but also for visitors and the population of the region. The main objective of the project is to classify the port of Dubrovnik as a group of leading Mediterranean tourist ports in all its features to create a quality tourist product. This should contribute to the overall tourist offer of the Dubrovnik area. The share of Dubrovnik on the wider Adriatic market of year rounds is growing and Dubrovnik is considered to have the potential, like Venice, to get the status of a destination that should not be missed. An essential element for achieving this goal is the development of port facilities that will greatly contribute to the port and tourist offer of the entire Dubrovnik-Neretva County.

3.3. Air traffic subsystem

The air traffic system through Dubrovnik Airport in Čilipi currently links the County with the rest of the world. The linking of the City with the airport in Čilipi to the high level of service is an investment priority. This is because Dubrovnik, despite the improvement of road connections, will continue to be an aerodrome destination with regard to the geographical distance from the major broadcasting areas. Therefore, air traffic will continue to be a key factor in tourism in the Dubrovnik-Neretva County. This circumstance indicates the need for airport training in spatial, technical, instrumental and functional terms for a greater volume of passenger and goods traffic, and safer, more environmentally friendly (noise) and traffic conditions less dependent on traffic, with new facilities (hotel accommodation, appropriate catering , processing plants). Therefore, it is necessary to fully instrumentally equip landing from the Grude direction and create specific conditions (construction) for these new facilities. Naturally, the current reconstruction of the Dubrovnik Airport as well as the introduction of new lines precisely emphasizes the significance of this issue. For example, the Republic of Croatia will again be directly linked to the United States through the Dubrovnik Airport after 28 years of age. Thanks to longstanding negotiations between the Dubrovnik Airport and American Airlines, the city of Dubrovnik and the US will be connected to the American city of Philadelphia in the current year.

In the segment of hydro transport, interest for this specific transport offer can also be found. For the region of the Adriatic, it still seems unobtrusive and unreal, precisely because such a form of transport has not yet lived in Croatia. Many analyzes such as cost-effectiveness, environmental impact, and other factors point to the attractiveness of such an offer. It is about creating a seaplane network for seaports in Dalmatia and on the islands, which will make significantly more and better connect all major destinations in the Adriatic under the guidance of European Coastal Airlines (ECA). Depending on the development and acceptance of seaplane services as a form of transport. The construction of a network of air routes is planned from north to south. It will connect islands such as Mali Lošinj, Cres, Rab, Dugi otok, Brač, Hvar, Korčula, Vis, Lastovo, Mljet and other islands with each other and with the mainland. The berth in Dubrovnik, which is likely to be a busy offer in the port of Gruž.

3.4. Railway traffic subsystem

Railway transport is planned to modernize the Ploče - Metković - Sarajevo - Osijek - Budapest railway lines on the international transport corridor Vc. According to the Road Development Strategy of the Republic of Croatia (2014), the possibility of building a fast-track Adriatic rail linking Mali Asia with Western Europe is foreseen. Potential positions for two stations in the County are: within the wider area of Dubrovnik - Osojnik, and in the broader area of Ploče. The reality of this plan is questionable given the lack of adequate cost-benefit analysis and the real needs of railway construction as a high-capacity traffic branch.

4. METHODOLOGICAL APPROACH

4.1. General settings

Solutions to the future traffic network of Dubrovnik-Neretva County are based on the relevant transport strategy. In this sense, the main pillars of the existing transport offer should be identified in the wider area of the City of Dubrovnik as well as other county centers. For this purpose it is necessary to create a database of existing and forecast trends in traffic sizes. The mobility of domicile inhabitants and the population residing in the observed area from tourism, business and other motives should be numerically expressed using the relevant scientific methodology. Future separate studies will be produced on the track of collected traffic-technical documentation that processes traffic systems in the wider area of the City (road, air, maritime). The analysis of spatial planning documentation will identify any deviations or mismatches in some current planning and project documents. For example, the territory of the City of Dubrovnik is divided into settlements or districts according to the valid planning documents. It covers an area of14,297 ha with 42,600 inhabitants. The division is aligned with the statistical data obtained from the Central Bureau of Statistics. The territory of the City of Dubrovnik consists of 32 settlements, and the largest agglomeration is Dubrovnik. In this area there are 28,113 inhabitants, or 65.9% of the population, in percentage. For this reason, territorial division into statistical circles has been accepted. The city of Dubrovnik is divided into 57 statistical circles, while only Dubrovnik is divided into 18 statistical circles. In the future study, the following areas should be analyzed and processed: to collect and analyze relevant traffic and technical documentation and to identify possible tolerances or mismatches in individual segments, to systematically process available traffic load data and to carry out additional measurements, predict the traffic burden trends for the future the stage of development of the Town of the County. Based on previous traffic and spatial analyzes, it is expected that a proposal for the evaluation of the network of transport infrastructure in the wider and narrower area will be expected. In the sphere of passenger and city public transport itineraries to apostrophize the existing bus systems of Libertas. From alternative modes of transport, consider the new city rail system type light rail with a connection to Dubrovnik Airport. Conceptually defined connectivity and interdependence at particular levels of proposed traffic systems. Existing and future studies of the transport model must provide answers, ie suggestions of the stage of realization of the entire transport system. The foreseen modes of transport should enable mutual integration into the ultimately integrated solution.

4.2. Methodology of determining transport demand with regard to tourism

Transport demand can be defined as the total demand for transport services that physical and legal entities want at all levels in one economic system. It can be achieved with certain conditions (price, spatial and temporal parameters, type of transport, quality of tourist service etc.) The volume and the organic composition of transport demand are determined by many factors, and their classification is proposed by many traffic research services authorities. Sublimation of all relevant parameters consists of two components:

structural changes in transport quality and structural changes in all segments of the transport offer. Global factors that determine transport demand as complementary to tourism activities can be considered as follows: technical - technological factors: quality and capacity of transport infrastructure, commercial speed, safety, reliability, regularity of transportation. Economic organizational factors in the size, composition and spatial distribution of workplaces, housing, tourist attractions, cultural and sporting contents and more. The quality and quantity of transport demand also have different strengths and directions of influence, so identifying and quantifying transport demand is a very complex task. The effects of mixing and diffraction of various interests, ie the interaction of causes and consequences in modeling transport demand, are quite important. In this situation, it is possible that a set of influential sizes for a predetermined size of transport demand may be used instead of one or more immediate determinants, but then the possibility of determining the specific impact of each variable on the required size is excluded. One of the indicators of supply and demand is the so-called. "Accessibility Index", which expresses the ease of access to a particular type of transport activity to a particular activity within the observed area or location of interest to the user of the means of transport. Different accessibility indices have been developed in some traffic studies, for example:

$$\mathrm{Q_{ij}} = \sum_{j=1}^{n} \mathrm{A_j F_{ij}}$$

where is:

Qij- accessibility index of the emission zone "and" to all other reception zones
$\mathrm{A_j}$- the emission index of the emission zone "and" to all other reception zones
$\mathrm{F_{ij}}$- the time travel resistance parameter from zone "i" in zone "j" with the subject means of transport:

$$F_{ij} = 1 \;/\; travel\ time\ "door\ to\ door"$$

n- number of zones

Accessibility index can be expressed as the number of itineraries that link individual zones, the frequency of individual movements of the vehicle and the area of the respective zone. Accordingly, the accessibility index in a gravity zone can be calculated by pressing the following pattern:

$$\mathrm{AI} = \frac{\sum_i \sqrt{\mathrm{N_{ij}}}}{\sqrt{\mathrm{A_j}}}$$

where is:

$\mathrm{N_{ij}}$- Accessibility index can be expressed as the number of itineraries that link individual zones, the frequency of individual movements of the vehicle and the area of the respective zone.

Accordingly, the accessibility index in a gravity zone can be calculated by pressing the following pattern:

$\mathrm{A_j}$- area of zone "j"

Likewise, access modality accessibility index in the given area je:

$$\mathrm{AI} = \frac{\sum_i \sqrt{\mathrm{N_{ij}}}}{\sqrt{\mathrm{A_j}}}$$

where is:

$\mathrm{N_{ij}}$- - number of line or free-transport overtime which stops at station "i" in zone "j"

All factors influencing the choice of travel method are not exhausted by the subject analysis. Neither the strength of the influence of each of these factors nor their interconnection was determined. The latest theoretical settings increasingly recommend the use of a complex method, known as the "Cost Benefit Analysis", which strives to bear in mind that the costs of building and maintaining traffic infrastructure must be borne by its customers, in proportion to the benefits they receive. This problem is most often solved from the point of view of determining the so-called methods. "Fair distribution" of transport infrastructure costs. Thus, the establishment of such a tax system that, taking into account the characteristics and purpose of certain categories of roads, will try to ensure economically stimulating and fair distribution of costs. Accordingly, it is necessary to determine those parts of the infrastructure network that have a distinct or predominantly commercial character. Such investments are considered as long-term safe business moves. In addition to investing in those parts of the infrastructure that are considered important for tourist purposes as a founding branch of the Dubrovnik-Neretva County, it is also important to choose the location of tourist facilities. The mentioned tourism is less stable in relation to other economic activities and branches for long-term planning. Political and economic conditions, as well as the security situation, will lead to difficulties in the projection of natural and financial indicators, as well as to its integral evaluation. The role of quantitative methods in the scientific analysis of this socio-economic phenomenon is the right path to the establishment of scientific knowledge. Below is a description of the procedure of selecting a project in tourism construction using the methods of operational research. The following real investment problem is assumed: N tourism sites are considered, in each project Ki projects are proposed, total financial resources for development of tourism are indicated by parameter b, some projects are connected, the decision maker wants to choose such a set of projects to maximize the overall expected profit. The mathematical model of this problem can be formulated in the following way:

$$\max \sum_{i=1}^{N} \sum_{j=1}^{K_i} d_{ij}\, x_{ij}$$

with limitations:

$$\max \sum_{i=1}^{N} \sum_{j=1}^{K_i} c_{ij} x_{ij} \leq b$$

$$x_{il} - x_{im} \geq 0 \qquad \text{za } i = \overline{1,N} \qquad j = \overline{1,K_l}$$

$$x_{ij} \in \{0,1\} \qquad \text{za } i = \overline{1,N} \qquad (1,m) \in P_i$$

where is:

N- number of tourist sites
K_i- number of projects at i-th tourist site
x_{ij}- an unknown size that receives a value of 1 if the jth project is selected at the i-th site, otherwise 0
d_{ij}- no-win profit if the j-th project is realized on the i-th site
c_{ij}- the price of the j project on the i-th site
b- total money resources
P_i- a set of linked-index projects on the i-th site

It is posing as a special problem of determining numerical values of individual parameters in the first order of the expected profit for the j-th project at the i-th location. In this example, the estimation methodology is missing, as this requires a special approach and, therefore, a separate analysis. The optimization process as a central starting point in the process of developing transport infrastructure facilities is a multiplier of the valorisation of a number of economic actions, which is also reflected in the process of valorisation of tourist potentials. This fact indicates that the process of optimizing the infrastructure of all branches of transport must be in the function of valorisation of the already accumulated accumulation. This aspect of the analysis contains an analysis in which they must find the place and the negative implications of the process of optimizing the construction of the transport infrastructure if the construction of the facilities itself was not realized in a way that would provide optimum benefit. For the realization of such major investment activities, the entire tourist economy and the entire transport system must be interested. So, the value of the tourist potential of the region under consideration must be thoroughly balanced with the entire accompanying transport infrastructure. The creation of sustainable urban and county transport requires the harmonization of economic development and accessibility and the improvement of the quality of life and environmental protection. In the Green Paper, the European Commission outlined five challenges for achieving the goal of sustainable urban transport: reducing downtime, reducing exhaust gases, intelligent urban transport, better access to public transport and secure urban transport. Achieving sustainable mobility is possible through a combination of different transport policy instruments from technology, space use, infrastructure, management, information to pricing. The advancement of technology contributes to the reduction of harmful exhaust gases and the reduction of traffic victims. The planning of mixed uses and the higher density of dwellings associated with public transport contributes to the reduction of travel times and the use of private cars. A well-planned transport infrastructure improves the overall standard of living, reduces traffic congestion and more. In the case of Dubrovnik-Neretva County, it is possible to route traffic directions, favor public transport, better exploitation of the sea as a transport medium and other measures. Improving the frequency of buses, network coverage and quality at lower prices increases the attractiveness and capacity of public transport. The ultimate goal in creating an integral transport service is the mutual and complementary functioning of all branches of traffic. Technical-technological integration and tariff union would provide an integrated transport service for all users, as well as the domicile population, as well as numerous tourists.

4.3. Integral conception of the traffic system of the Dubrovnik-Neretvan County

In general, the integration of the passenger transport system is aimed at logically linking existing and new modes of subsystems to the area where integration with a unique transport organization is possible. In most urban agglomerations in Europe and the world, the cornerstones of a single transport system in the public transport segment are modes of mass transportation, eg trajectory systems due to technological and economic advantages. Urban transport means (buses, taxis) bring passengers to the common intermodal terminals, which are transferred to desired micro-allocations: The positive effects of traffic integration are as follows:

- shortening the average travel time,
- reducing the switchover at the transition points between the two traffic subsystems
- increase the commercial travel speed,
- more rational use of power,
- reducing environmental pollution,
- landing of road roads,
- the degree of road transport safety is indirectly increased,
- more rational utilization of urban space with the aim of protecting the environment.

Apart from the lack of awareness of academic and academic publicity, one of the reasons why this issue is not adequately addressed is due to the insufficient activity of political bodies at the local or regional level. In the field of legislation, it is necessary to accept the possible and very desirable adoption of a legal act that would accelerate and simplify the procedure in all segments of the implementation of the integrated turnover model (Figure 2).

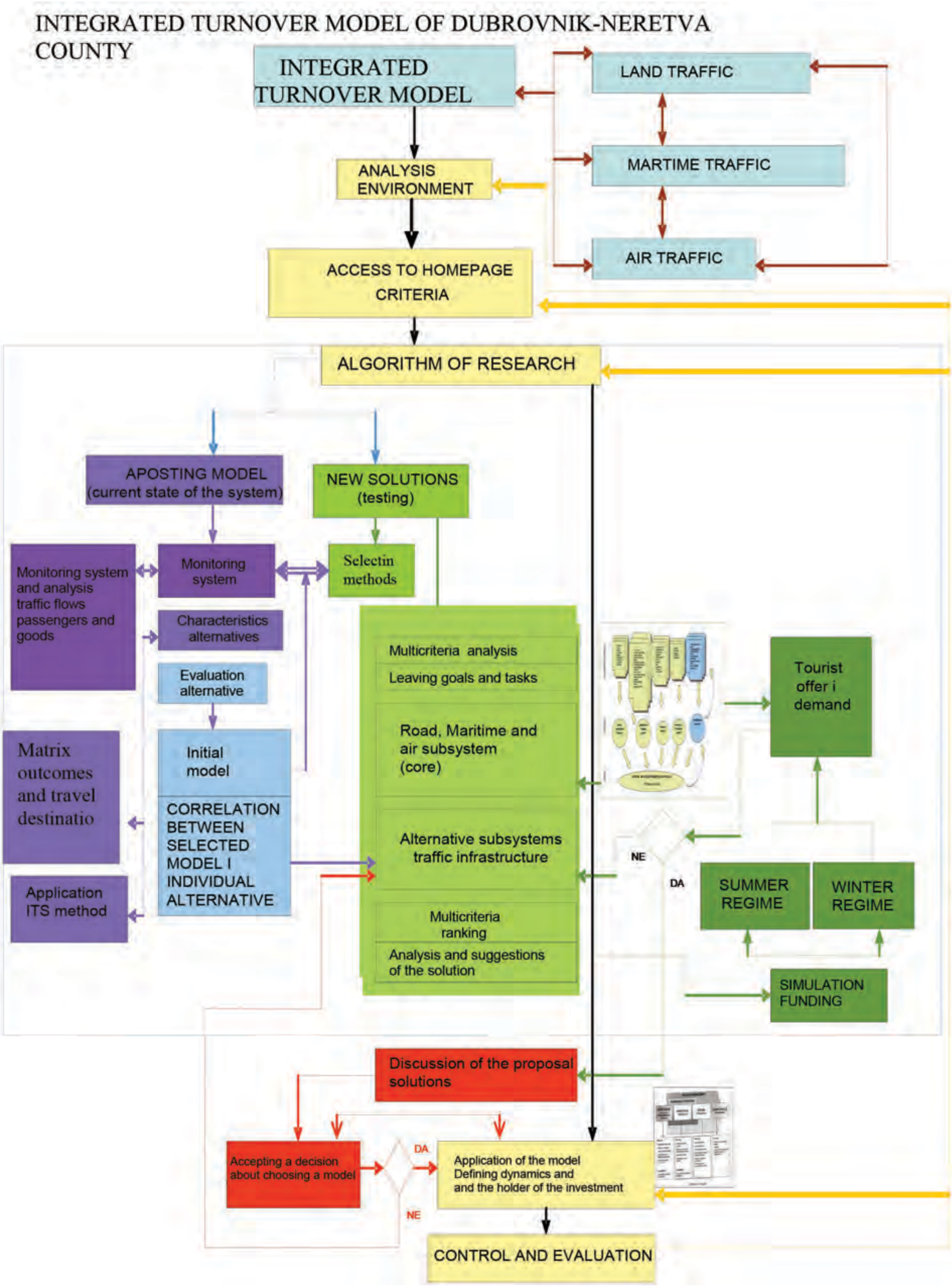

Figure 2 Integrated turnover model of Dubrovnik-Neretva County

Source:created by authors

Thus, the legal basis would be reflected in the implementation of the Law on Integrated Public Transport of Passengers. The same should give the legal framework and conditions for the establishment of integrated passenger transport. Primarily, it refers to defining the rights and obligations of all involved executives ie entities in the constellation of contracting legal and economic relations between carriers and local / regional self-government units. A key assumption is the efficiency and attractiveness of integrated passenger transport that is legally based, in favor of the local population and tourists in the domain of social or communal standards. In the broader sense, the integrated public activity of public interest is based on EU legislation, the Constitution of the Republic of Croatia as well as the strategic documents of transport development (The Transport Development Strategy of the Republic of Croatia for the period 2014-2030). The postulates that determine the fundamental settings of the integrated integral model of transport on the example of Dubrovnik-Neretva County are as follows:

- logistic transformation of transport subsystems resulting in the integration of technological segments: urban and county bus transport, Dubrovnik cableway and maritime transport, air transport combined into a common, harmonized transport system,
- in the liner shipping sector, the introduction of a common, single fleet on all public unimodal and combined transport lines,
- to encourage the introduction of an integrated system used by developed countries of the European Union and the world, and in particular on all the basic strategic European documents (White Paper),
- Introduce tactical timetables in line traffic, ie depart from each point at regular intervals (eg every 10, 20, 30, 60 minutes etc ...),
- increase the number and common stops (terminals) that stop different types of public transport (bus, cableway, ship, aircraft) with a simple and efficient transfer between individual modes of transport,
- scheduled in the public transport system, and allow for a quick resumption of travel after the transfer (with minimal time losses),
- optimal linking of the town center of Dubrovnik with the surrounding rural area of the so called suburban ring,
- to enable the long-term development of the County's overall development with a higher degree of realization of spatial planning projects.

Local and regional government units should be the initiators and instigators of all administrative procedures by engaging in finding sources of funding for the realization of the project concerned. Support for such ambitious ventures often comes from European Union funds, and with adequate efforts and engaging access to all relevant factors, it is important to insist on the establishment of an innocent transport model.

4. CONCLUSION

The traffic connection of the Dubrovnik-Neretva County with the associated county center of the city of Dubrovnik with the rest of Croatia is not satisfactory. The arguments for this claim are: poor road infrastructure, poor or no connection in winter with shipping lines, dependence on air transport, and lack of rail transport modes Due to inconsistent transport policies and (mostly) unplanned construction, traffic solutions were accompanied by improvisations that led to the problem which have accumulated for years. The focus of the problem is the City of Dubrovnik, where the summer season was marked by traffic collapse due to the crowd guests. Namely, urban roads hardly submit traffic of domestic population in the winter months, and the real problem occurs in the beginning of spring to mid-autumn. This is where the season of arrivals of cruise ships arriving in the Dubrovnik Port or anchors in front of the old city port begins. All tourists are primarily oriented towards visiting the old town core, and the only possible means of transport are: buses, cabs or public transport. When the number of means of transport circulating by city roads joins pedestrian traffic, if tourists who have come to visit in their own arrangement, or their own car, reach the upper limit of the capacity of the transport infrastructure.

The recent realization of the Peljesac bridge is changing the traffic image of the southernmost region of Croatia. The importance of the traffic network of the Dubrovnik-Neretva County with the rest of Croatia shows more than 120 thousand people living from Korčula to Prevlaka and numerous tourists. In general, the basic road transport infrastructure on the land should also join the problems of maritime and air traffic subsystems. In this way, the subject matter should be treated integrally, because only in the combined technology of various traffic modalities is the final solution key. The road towards achieving this goal begins with a thorough research of current and new, alternative transport modes. For the synergic effect condition is achieved transport technological integration and tariff union.

REFERENCES

]1] Baričević, H. (2001): Land transport technology, Faculty of Maritime Studies, Rijeka.
[2] Baričević, H (2003).: Transport in Tourism, High School for Tourism, Šibenik.
[3]. Đukić, A. and Jerković, S (2008).: Influence of tourists from cruise ships in the historical core of the city of Dubrovnik.
[4] Sustainable transport strategy of the City of Dubrovnik, (2008), Formaplan, Transport Metropolitans de Barcelona (TMB), Trames d.o.o.
[5] Traffic study Dubrovnik 1. Phase, (2009), IGH Institute d.d .
[6] Spatial plan of Dubrovnik-Neretva County (2010); Amendments; Institute for Physical Planning of Dubrovnik-Neretva County.
[7] Spatial planning arrangements of the City of Dubrovnik, (2007), Amendments; Urbos d.o.o .
[8] General urban plan of the City of Dubrovnik; (2007), Amendments; Urbos d.o.o .
[9] Urban Planning Plan of the Business Center Gruz; (2008),Urbis 72 d.d
[10] Libertas Dubrovnik d.o.o .; www.libertasdubrovnik.hr
[11] Port Authority Dubrovnik; http://www.portdubrovnik.hr
[12] Airport Dubrovnik; http://www.airport-dubrovnik.hr
[13] Sanitat Dubrovnik d.o.o .; http://www.sanitatdubrovnik.hr
[14] Public garage Ilijina glavica, http://www.ragusaparking.hr
[15] Central Bureau of Statistics, www.dzs.hr
[16] State Geodetic Administration; www.dgu.hr
[17] Turistička zajednica Grada Dubrovnika; http://www.tzdubrovnik.hr/

CONTROVERSIES IN THE S/S STEFANO MULTIDISCIPLINARY RESEARCH

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Summary

The multidisciplinary and multicultural issues of the Dubrovnik-Rijeka sailing ship Stefano have become controversial in many aspects of the prudent approach. Though opinions are still extremely debatable in the scientific and professional communities, they remain areas of active research. However, the arguable global maritime history makes it difficult to conduct information and highlight intriguing topics. A stronger thesis has been proposed and defended by some researchers over recent decades. The books and papers under review engage with and react to the swirling debate about influential and controversial body of ideas. Relative agreement among experts is the lowest by now. Ideally, many international scholars can extend their findings to wider public before conclusions. Speakers may verbally indicate their unease with expressing controversial view. The issue is complex and answers the question of who should have the authority and responsibility to determine the completed research. In particular, it seems still controversial whether the ship is from Dubrovnik or Rijeka, whether the issues are of the Italian, Australian or Croatian maritime heritage? The central research questions are about the crew, the ship remains, as well as the location and cause of the shipwreck, in north-west coast of Australia, on 27 th October 1875. However, many will welcome productive debate and clarification of the hypothesis. Taken together, our quantitative results are important, providing insights into this complex problem. The qualitative methodology is used with inductive and comparative methods, analyses of case studies and historical documents. Our analysis conclusions do not support several of the controversial and provocative claims in the literature. The major contribution has been done for forthcoming publications on the maritime history of the community, especially, the role of Croatian cultural and maritime heritage within the global environment.

Keywords: multidisciplinary research, multicultural environment, s/s Stefano shipwreck, controversies, Croatian maritime heritage

1. INTRODUCTION

Based on the research of past events, we discover relevant perceptions about the present and the future. The sailing ship s/s *Stefano* is an excellent case study, because someone out of Croatia has rescued a 19th-century ship and his crew, including them in modern everyday life, making active a tiny part of the Croatian heritage. Although many Croats have never heard of this ship, s/s *Stefano* has become popular all around the world, first in the world of media, and then among scientists and experts from Australia to America. The implementation is a new model of heritage communication in a global environment. After a hundred and twenty-five years, Miho Bačić, a cadet and one ot the two survivors, became the main hero of the same story, in his grandson Gustave Rathe's book *The Wreck of the Barque Stefano off the NW Cape,* 1875. Gustave Rathe was a retired US Navy Officer. The book has been devoted to his mother, Euxenia Baccich Rathe. She was the second child in the family of Miho Bačić. Two Miho's daughters were born on October 27th for the anniversary of the shipwreck: Euxenia in 1890, on the fifteenth, and Anna on the twenty-fifth anniversary in

1900. This strange coincidence influenced Miho to choose the name of his first daughter Australia. But his wife, who studied languages, suggested a more appropriate name Euxenia (Greek eu-xenos, i.e, respect for foreigners). That name reminded them of down-under Australian native people who had saved the lives of her husband and father of their children. Miho's grandson Gustave showed the same respect and gratitude for the white people, as well as the dark natives from the far country, during all his life (+2009). Today his wife and sons continue with the same gratitude. Successful communication of different ethnic groups contributes to ethnic tolerance and cooperation. Especially today, making efforts in that sense, we do hope to come up with affirmative answers to the following questions: Will we notice any progress in communication with the Italian community in Perth by the next anniversary of the s/s *Stefano* shipwreck in 2020? Or this will be realized by some future generations? In one of the last articles about the s/s *Stefano*, the same author points out that the *Stefano* crew members could not even imagine how the shipwreck remains in areas of active research over the centuries. The books and papers under review engage with and react to the swirling debate about influential and controversial body of ideas, in the form of sharp opposition to the interpretation of historical facts, methodologies and results of archeological submarine explorers.

2. CONTROVERSIES OF THE RESEARCH SUBJECT S/S *STEFANO*

The subject of the research is a sailing ship, s/s *Stefano*, built in Rijeka Brazzoduro shipyard, in 1873. Information comes from Paris-based international ship classifications annual publication the Registre Veritas from 1875/76. The ship had JRSM and a navigation license (Patent No. 22) of January the 3 rd 1874, for 857 tons. She was a single deck vessel, magnificent, twice taller than an average English ship, 51.9 meters long, 10 meters high and 6.3 meters wide, orlop beams of oak, larch and beech, bolted together with yellow brass and galvanized iron. Surveyed and decorated with brass in London, in June 1875, the *Stefano* was classified as the first class ship. Chartered for Hong Kong with 1300 tons of coal, she sailed from Cardiff, on July 31st 1875. It was her last, tragic route, fifteen thousand miles long.

Having used Australian and Croatian Archive sources from Perth, Dubrovnik and Rijeka two respectable historians Graeme Henderson, Australian and Radojica Barbalić, Croatian describe the *Stefano* in their books. By now, there is no a picture of the s/s *Stefano*, nor a technical drawing. The barque *Stefano* was shipwrecked near Point Cloates, off the north-west coast of Australia, on 27th October 1875, at 2:00 o'clock in the morning. What was the cause? Just bad weather conditions, wrong route, sailor on duty, or something else?

Two sailors (of 17 strong crew members), Miho Bačić and Ivan Jurić survived six months horrible weather, hunger and exhaustion, thanks to God and the indigenous Aboriginal people. The survivors had been living with Aborigines for three months. They were picked up and brought to Fremantle by cutter *Jessie* with Capt. Charles Tuckey, on 18 th April 1876.

They stayed for a while in Fremantle, worked and earned money for returning home. First, they went to Ceylon by a small steamship *Georgette*, moved to the steamship *Indus*, arrived to Suez, where the Austrian Consulate sent them by train to Alexandria. Once again, they boarded a steamship, on their route to Trieste, before coming back to their families in Dubrovnik, in October 1876. Miho continued with maritime education and practice, so far. Since 1881 he became a captain on two ships *Antal* and *Risorto*, both owned by his uncle Nikola. The maritime crisis forced Miho to find a job abroad. So, he moved to America, founded his family and died on the eve of the Second World War. The main source for the *Stefano* research is the *Manuscript,* an objective and historically authentic document, told as confession by two survivors, after returning to Dubrovnik, in 1876. Pater Stjepan Skurla, a Jesuit monk and a canon had listened to both sailors, independently, and wrote the true, authentic and objective story of their lives in Italian, lingua franca, the official language of the period. The Bačić's descendants own their copies of the *Manuscript,* as a part of the family cultural heritage. In 1920, Miho's wife translated the *Manuscript* from Italian to English.

Other sources are Miho Bačić's letter, sent to his parents in Dubrovnik, as soon as he had arrived in Fremantle, on 16 th May 1876. For a long time, kept by Miho's relatives on the island of Lopud, and the votive painting *Jessie* which Miho Bačić and his father gave to the Church of Our Lady of Mercy in Dubrovnik as a gratitude to Our Lady for the salvation. Italian description on the painting is also a subject of controversy. The painting describes the cutter *Jessie* rescuing the two *Stefano* survivors from Bundegi Beach, in April 1876.

The *Stefano* shipwreck has become the subject of research for many scientists. But, numerous controversies emerged with each new research and interpretation. We tried to select them in three main categories. The first is related to the subject of the survey, i.e. the sailing boat herself, trying to answer research questions: Is the s/s *Stefano* from Dubrovnik or Rijeka? What is the origin of crew members? Controversies caused by the votive image. Does the event belong to the Italian or Croatian historical heritage? The second category of controversies relates to the state of present research and the results. We try to clarify these research questions: Are the underwater remains of sailing ship the component parts of the s/s *Stefano* or some other ship? Has the current research correctly locate the shipwreck? What is the real cause of shipwreck: human error, weather conditions or something else? The shipwreck links with native Australians have many controversies. The third category analyzes the research methodology and tries to find solutions to the possibilities of future research and new models of scientific methodology.

2.1. Sailing ship from Dubrovnik or Rijeka? Italian or Austrian ...?

In his book about Rijeka sailing ships and shipyards, PhD Radojica Barbalić, a historian and manager of Rijeka Maritime and History Museum from 1973-1979, mentioned all details about the *Stefano*, according to Bačić's statements and the Registre Veritas of 1875/76, as the vessel was built in Rijeka, at Brazzoduro Sušak shipyard. At the time, Rijeka was a highly developed shipbuilding center under Austro-Hungarian Monarchy. So, the ship was registered in the Monarchy. At the same time she sailed under the Austrian and Croatian flags. It is owned by Nikola Bačić (16), Egon Cunradi (2), Francesco Lemutha (2), Antun (Matov) Kovačević (2 1/2) and Fran (Matov) Kovačević (1 1/2). A captain was Vlaho (Matov) Miloslavić. Nikola Bačić from Dubrovnik moved to Rijeka, became a respected citizen and businessman. He was married with a daughter from the Vranić's, a prestigious Rijeka marine family. In the early 20 century, Nikola Bačić owned eight long sailing ships and was one of the strongest shipowners at the time. Capt. Bačić was the commander of the steamship *Croat*, successfully sailed on the route between Senj and Rijeka. When businessmen from Kraljevica established a "Steamship and Naval Cooperative", in 1876, shipowner Nikola Bačić from Rijeka connects Istrian ports with Rijeka by steamship *Liburno*, built in 1873., sailed to 1874 and sold to foreign (Italian) owners in early 1875. The 19th century strong shipbuilding activity in Rijeka was also developed by Josip Bačić-Belac. Nikola's son Stjepan was the first captain on the sailing ship, having his name *Stefano*. Unfortunately, Stjepan Bačić was a captain only on the first voyage, because he became ill and died at the age of 24. The other captain of the same ship was Vlaho Miloslavić from Dubrovnik, who did not return from the trip to Hong Kong, as was shipwrecked in 1875. For a long time, nobody from Rijeka, nor Dubrovnik, knew the fate of the s/s *Stefano* and the crew, until June 1876, when Miho Bačić's parents and his uncle received his two letters, describing the whole event, and the names of all the crew members, and their tragedy. Many ships of the period got name *Stefano*. Usually, the surname of the owner would be added. There was the barque *Stefano*, 466 t, sailed under Russian flag, and since 1872 under the Austrian, when changed her name to *Stefano Kovačević*. The owners were the Kovačević's from Pelješac peninsula, Luketa and Jakovljević. Captains were Liborio Jakovljević, Ivan Gabela and Matković. The ship was sold in Marseille, 1879. Nava *Stefano Flori*, 550 t was built in Livorno, 1854, owned by Peljesac family Flori from 1855. The captains were Štuk and Gurić. Barque *Stefano Mimbelli*, 699t was built in Trieste, 1870, owned by Pelješac family Mimbelli, since 1870, sailed under the Russian flag and a captain was Krstelj.

2.2. Origin of the crew

Although the Australian register of the first Croatian immigrants gives the barque *Stefano* sailors names, their Croatian origin is not mentioned. At the time, they were Austrian or Austro-Hungarian subjects, people did not declare themselves as Croats, and in the registers were mentioned as 'Austroungarico' in Italian. The names were first altered by Italian transcription, and then they got English versions. Later, many were enlisted as Yugoslavs, which also had the problem of discovering their origin. The reason why little is known about the first Croatian immigrants is that there is no complete study of their life and their role within the Australian society. On the contrary, it has been very well done for Italian immigrants. The number of Croats has been reduced, constantly. Kapetanić and Vekarić explained the origin of the s/s *Stefano* crew and Stjepan Ćosić the socio-historical background of the period. Members of the crew were all Croats, most of them from the Dubrovnik area (16). The only one was an English boy, Henry Groiss (12yrs) from Cardiff, Wales, where a captain Vlaho Miloslavic embarked him immediately before leaving. A grandfather of the first officer Carlo Costa was from Genoa. Miho Bačić's grandfather moved to Dubrovnik from Blato on the island of Korcula in 1814. Vlaho Miloslavić was from the old family of the village Makoše in Zupa Dubrovacka. Ivan-Pavle Radovic was from the old family of Potomje on the peninsula of Pelješac. Ivan Jurić's father Nikola moved to Oskorušno from Lokvičići near Imotski. Nikola Brajević was from the old Mikulići family in Konavle, near Dubrovnik. Baldo Vukasinovic was from the old family of Lisac in the Dubrovnik area. Ivan Lovrinović was from the old family of Kuna on Pelješac peninsula. His father moved to Dubrovnik in the1830's. Toma Dediol was from the old Juričević family of Kučišta. In the 18th century Juričević was nicknamed Dediol, which later turned into surname.

Some more details about Carlo Costa's origin. His grandfather was Italian from Genoa, moved to Dubrovnik in 1799 and married Croatian girl Lucija Vilenik. Carlo's father, Josip Carlo Costa, married another Croatian girl Lucija Brešan from Slano, near Dubrovnik (Dubrovačko primorje). So, one grandfather of the first officer Carlo Costa was Italian, and another Croat, but both grandmothers were Croatians. At the Western Australian University, some scientists of Italian origin claim the opposite, as PhD Melville Sala, who published the book *Stefano Castaways* in 2009, distorting the historical facts, changing s/s *Stefano's* Croatian historical and cultural tradition and Croatian origin of the crew, as well. His main argument is the usage of Italian language which was official. He points out that the crew members were Italians because their names were written in Italian. Such a claim denies historical facts. Dubrovnik and its surrounding area were parts of the Austro-Hungarian Monarchy in the 19.ct. The area of the former Dubrovnik Republic uses the Italian language in administration, although most Croats (more than 95% of the population) in Dubrovnik do not know that language, at all. Only educated people know it. In villages of Dubrovnik (with about 70% of the population) priests, doctors and only some individuals know Italian. Being the official language, the names and surnames in the documents were written in Italian. Moreover, Croatian names in the documents were translated into Italian , like Antonio, Pietro, Stefano, Biagio etc., but nobody in Dubrovnik called them so, but Antun, Petar, Stjepan, Vlaho, etc. This was best proved by court processes. Basic forms of court files, introductory parts, judgments etc. were given in Italian, but the statements of the witnesses were written originally in Croatian. Surnames were written in Italian, so Jurich instead of Jurić, Bacich instead of Bačić, etc. The reason was not that Italians lived there, but the usage of Italian in administration, contrasting the spoken Croatian language. The family of Miho Bačić originates from the island of Korčula, a place Blato, one of the oldest settlements on the island. According to data from correspondence and conversations with the Bačić family descendants who moved to America (Anne Gousoline and her husband, visited Dubrovnik in 2010. Her son with family came later) we draw one part of the Bačić's family tree.

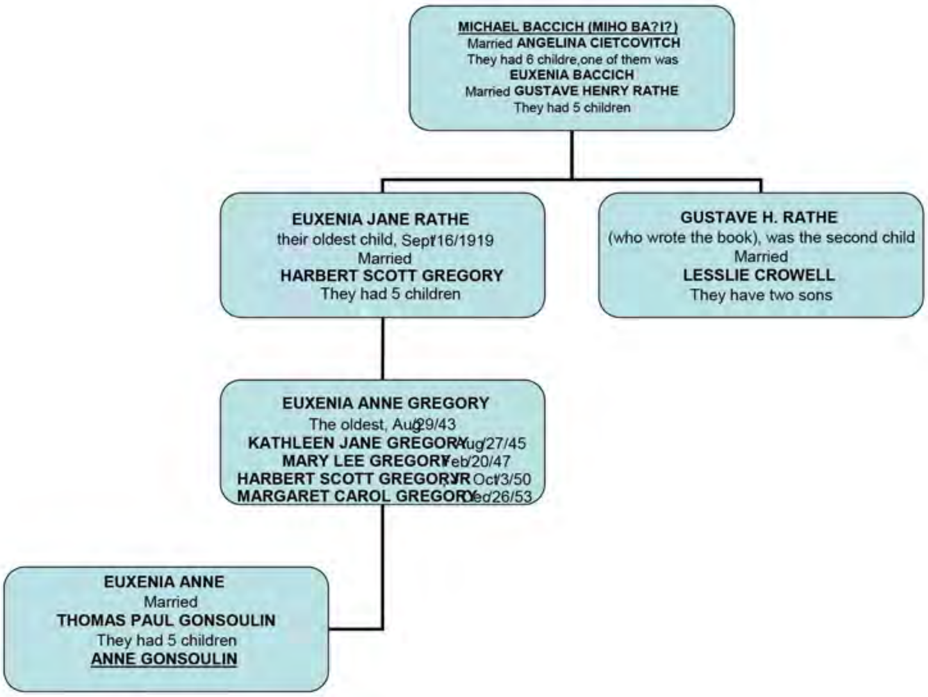

Diagram 1 The Bačić's family tree (one branch)

Source: Correspondence with Anne Gonsoulin, 2010.

EUXENIA BACCICH MARRIED GUSTAVE HENRY RATHE

THEY HAD 5 CHILDREN

MY MOTHER, EUXENIA JANE RATHE WAS THEIR OLDEST CHILD 9/16/1919
MY UNCLE GUSTAVE H. RATHE (WHO WROTE THE BOOK) WAS THE SECOND CHILD

EUXENIA JANE RATHE MARRIED HARBERT SCOTT GREGORY

THEY HAD 5 CHILDREN

EUXENIA ANNE GREGORY WAS THE OLDEST	8/29/43
KATHLEEN JANE GREGORY	8/27/45
MARY LEE GREGORY	2/20/47
HARBERT SCOTT GREGORY, JR	10/3/50
MARGARET CAROL GREGORY	12/26/53

EUXENIA ANNE MARRIED THOMAS PAUL GONSOULIN

THEY HAD 5 CHILDREN

KATHLEEN JANE MARRIED JOHN NEWCOMB –THEY HAD 2 CHILREN
MARY LEE MARRIED LENARD LEVIS- THEY HAD 3 CHILDREN—JASON IS THEIR 2ND CHILD
SCOTT MARRIED SUSAN BLACKWELL—THEY HAD 2 CHILDREN
MARGARET MARRIED NICHOLAS DREYFUS—THEY HAD 2 CHILDREN

According to Muljačić and Šimunovic, names are the most distinctive linguistic signs, the most important signs of identity and the time in which the naming occurs. The name is social act from which important socio-linguistic messages radiate. In the period from 1870 to 1880 we research the fund of Croatian male names in the birth books, of different Croatian settlements, along the Adriatic coast. Slavic names disappeared and were replaced by sacred equivalents of the Christian names, in Croatian or Italian translation. These names have lasted for long, even by now, being pronounced in the old way, but in church books registered in a new form, such as Božo - Natale, Cvjetko - Florio, Krile - Kristo, Rado - Rafo (sometimes Allegretto), Rusko - Roko, Vido - Vito (Vicko), Vuko - Luka and Ivan (Đivan).

Table 1 Croatian Male names in the 70's&80's of the 19 th ct

Name	Number	Percentage
Ivan	611	14,95
Antun	483	11,82
Josip	272	6,66
Petar	261	6,39
Nikola	246	6,02
Mato	243	5,95
Stjepan	200	4,89
Marko	130	3,18
Juraj	129	3,16
Mihovil	110	2,69
Jakov	93	2,28
Franjo	84	2,06
Andrija	78	1,91
Kuzma	75	1,83
Luka	61	1,49
Lovro	57	1,39
Pavao	56	1,37

Source: Birth books 1870.-1880.

Miho Bačić (76 yrs) was interviewed by a journalist from Zagreb, 1935 and said: ‘Of course I'd rather be in my beloved Dubrovnik, but everything does not happen in life, as you like. Life is compromise. Anyway, I'm here, in peace. I have six daughters and a son. He runs my job, and I relax, I read and wait. My wife died ten years ago. This is a long, long journey from my birth in 1859 to today. ’One week after this conversation, in December 1935, Miho's long overseas life travel came to an end. His grandson Rathe describes him: ‘His early years were full of excitement and adventure. He was well-educated when few people had that opportunity. He spoke five languages when he was only twenty years old, and at the age of twenty-two he was a captain of a sailing ship. Brave to survive tragic shipwreck, he was a good, beloved husband and father, as well as the only one of my grandparents whom I knew.’

2.3. The votive painting *Jessie*

The votive painting *Jessie,* 80X55, *oil on canvas, 1877* by Bazilije Ivanković (lived in Rijeka), a sailor and a famous painter of Croatian ships, is kept at the Capuchin Monastery Votive Pictures Gallery of the Church of Our Lady of Mercy in Dubrovnik. The painting describes Western Australian Exmouth Gulf, Bundegi Beach, full of dark native nomads and two *Stefano* survivors. Capt. Charles Tuckey’s cutter *Jessie* rescuing the two, Miho Bačić and Ivan Jurić, on 18 April 1876 what is described in the bottom of the painting. Italian description on the painting has become a subject of controversy. The word ‘*among* natives’ has provocative meaning for opposing opinions. This is the Croatian translation:

Zavjet učinjen Bl. Gospi od Milosrđa od Miha Bačića iz Dubrovnika i Ivana Jurića s Pelješca, dvojice preživjelih od posade barka Stefano, pod zapovjedništvom kapetana Vlaha Miloslavića, koji se razbio 27. listopada 1875. u blizini rta Point Cloates u Australiji. Njih je poslije šest mjeseci strahovitih patnji, pretrpljenih među urođenicima na toj obali čudom spasio engleski kuter *Jessie* 18. travnja 1879. kojim je zapovijedao kap. Charles Tuchey...

The painting descriptions in the press, in the 40's of 20th ct. have negative conotations towards Aboriginal tribes.

Some members of the present Italian community in Western Australia, moreover, some scientists among them, still point out that the painting, the *Stefano* and the crew belong to Italian cultural heritage. The main reason for that is Italian language of the *Manuscript* and on the painting.

Debates spread out during and after occasion of opening the new Western Australian Maritime Museum in Fremantle, and the monument for our sailors, in the beginning of the 21st ct. There were public complaints by Croats in Australia and Mr Vjekoslav Karlovčan, an ambassador of Republic Croatia in Perth, who asked the most outstanding Croatian historians and scientists, among them Nenad Vekarić and Stjepan Ćosić to clarify the whole case, what they accepted and gave the written explanation, based on the serious scientific research.

Pater Nikola Stanislav Novak, a guardian of Capuchins Monastery in Dubrovnik brought the *Jessie* painting to be exhibited in Western Australia during opening occasion of the New Maritime Museum in Perth. Educated in Italy at prestigious academic institutions, with great knowledge of Italian culture and language, he translated the *Manuscript* into Croatian, describing the *Stefano* true story, told by Miho Bačić and Ivan Jurić, the only two survivors.

2.4. Shipwreck links with Aboriginal tribes

The west coast of Australia was the first part of the continent to be seen by European sailors, sailing east of Africa over the Indian Ocean or the South Pacific. The shipwrecks that took place in the waters of the Southeast coast of Australia had more chances for rescue than those along the uninhabited West coast. In the last quarter of the nineteenth century, there were more than 1800 shipwrecks in Australian coastal waters. Point Cloates has become famous by shipwrecks. It is assumed that in the period of seven months, at the time of the *Stefano*, there were five shipwrecks in the same place. Seven members of the *Stefano* crew lost their lives, immediately, while struggling with stormy wind and sea, hoping to leave the wrecked ship. Ten of them swam to the Australian coast, where their tragedy started while trying to survive. Only the two managed to overcome hunger, thirst and exposure to horrible weather conditions. Fortunately, Aborigines came along and helped them survive. They lived together with the tribe until spring, 1876, when a strong wind forced cap. Charles Tuckey, a pear diver, to get his cutter *Jessie* to the shore (Exmouth Gulf). Among dark natives on the shore, two white men could be noticed, neglected, half-covered, exhausted, burned by sun. Capt. Tuckey returned them to civilization after seventeen days sailing. When they passed by the brick *Alexandra*, shipwreck message was written with chalk on a board. It was Capt. George Vinal who first brought the news about the *Stefano* shipwreck to the public.

There has long been a belief that Aborigines were hostile to the *Stefano* sailors. It was influenced by attitudes towards the indigenous population. Only the latest research, which is still in progress, especially the conversation and living together with Aborigines, confirm the opposite. The natives protected the sailors and helped them survive. They fed them with spring water, shellfish, turtle eggs, fish and various berries. Natives were very kind-hearted and generous. Some have become their loyal friends, healing their sunburns and wounds on the soles, stomach ailments, etc. Besides caring for their physical health, they also worried about their mental state, giving sailors joy, playing together, singing, dancing, learning their language, and vs, hunting, preparing meals and eating together. During the 20th century, public interest in the shipwreck story has been increased. The upcoming news about the *Stefano* story, based on Miho Bačić's letters and the

Manuscript were used by several authors. Niko Štuk wrote the most. His views changed with changing of public opinion. His critic was Ivo Frano Lupis-Vukić. So, N. Štuk started to use the same terms as Ivan Lupis-Vukić, in his later articles.

Table 2 Štuk' s description of the s/s *Stefano* story

The event Stefano was first described in these words (N. Štuk):
- physical and mental suffering, a painful odyssey, a grievous mood
- a tragic case, a terrible event
- dying at speed, dying among savages, in the angry cannibals claws
- the fear of being eaten by cannabis was transformed into later articles in 'suffering hunger and thirst, losing strength and skeleton, and dying of thirst and starvation'

Source: Croatian press in the 20 th ct.

Table 3 Lupis-Vukić's description of the s/s *Stefano* story

Ivan Frano Lupis-Vukić criticizes Štuk and thus describes the same event:
- the most memorable story from our naval history, more fantastic than any fiction
- shipwreck sailors are called 'roadblock'
- instead of the term 'savages' for Aborigines, they are called 'natives'
- then 'good native tribes'
- our sailors protectors

Source: Croatian press in the 20 th ct.

Table 4 Contrasting Lupis and Stuk descriptions

Contrastive analysis of the most common terms in articles 1937-1941 I.F. Lupis and N. Štuk:
- the most memorable story, the painful odyssey, the tragic case↔ miraculous salvation
- wild people, wild natives, cannibals ↔ native nomads, good native tribes
- in the angry cannibals claws, cannibals slaves ↔ our sailors protectors
- black natives in the form of wild beasts, are not complete human beings ↔ generous and benevolent people

Source: Croatian press in the 20 th ct.

Table 5 Australian headlines and subheadlines in the 21st ct

Descriptions of the *Stefano* event in the 21 st ct. : Headlines and subheadlines of the Australian press
»Shipwreck tale of survival«
»Starving sailors turned to cannibalism«
»Tragedy of the death ship manned by boys«
»Ghost Hunters of the Deep«
»Historic wreck in waters shared with sharks«
»Underwater trail marks dive sites«
»Art illustrates shipwreck tale«
»The Resurrection of the Barque Stefano«

Source: Australian press in the 21 th ct.

3. RECENT REASEARCH

Scientists and professional experts collaboration from Australia, America and Croatia has been developed, involved in finding, studying and protecting the local cultural heritage on the world cultural scene. The most outstanding, a leader of all the *Stefano* projects and by origin from the island of Korčula (like the Bačić's), is PhD Joško Petković, from Murdoch University and a director of National Academy of Screen and Sound (NASS), member of Australia Screen production Education and Research Association (ASPERA), founding member of Barque Stefano Yinikurtira Foundation, and editor of on-line *Stefano* trails - documents, pictures and films:

http://nass.murdoch.edu.au/docs/STEFANO_EDITING.pdf
www.stefanocybertrail.com.

In June 2011, Petković had several lectures about 'The *Stefano* once and now, at the University of Dubrovnik and Capuchins Monastery & Our Lady of Mercy Church Museum, presenting the results of his latest research in this area. It was continuation of Dubrovnik University Project 2010 "Connections of the Croatian Maritime Heritage with Anglo-American and Australian", celebrating several anniversaries: the 90 th of the Maritime Foundation - Ivo Račić, the 90 th maritime journal foundation of 'International Journal of Maritime Science and Technology – Naše more', the 50 th of Dubrovnik High Maritime Education and the135 th of the s/s *Stefano* shipwreck. Members of Argosy Club, Mladen Mitić and Branko Vekarić built the first barque *Stefano* model, presented at many exhibitions, and now exhibited in the Museum Gallery of the Capuchin Monastery in Dubrovnik, close to the votive painting *Jsesie.* Another member of Argosy Club, Mario Marčinko painted *the Stefano* wreck painting, given as a gift to the same Museum and Gallery. The next phase of the research was realized with a new project 2015, presented in Australian and Croatian three conferences: the first in April, 2015 in Perth - collaboration with Murdoch University; in Dubrovnik, June – collaboration with the University of Dubrovnik and in Split, September - collaboration with the University of Split.

NATIONAL ACADEMY OF SCREEN AND SOUND RESEARCH CENTRE
MURDOCH UNIVERSITY
IN COLLABORATION WITH DUBROVNIK UNIVERSITY,
DUBROVNIK MARITIME MUSEUM
AND IN ASSOCIATION WITH THE
BARQUE STEFANO YINIKURTIRA FOUNDATION

Stefano Coast

CALL FORPAPERS
for a
The Ningaloo Trail: Discovering *the Stefano*
(for a 20-30 minute presentation)
18-19 April 2015
Venue: TBA
Perth, Western Australia

The remote Ningaloo Coast is one of the most impressive coastlines in the world. It contains the longest fringe coral reef in Australia and its pristine beauty is protected by a series of marine parks. In June 2011 the World Heritage Committee declared the Ningaloo Coast, including Cape Range National Park, to be on the World Heritage List.

In 1875, when this coastline was still largely unexplored by Europeans, it became the setting for a most dramatic shipwreck story involving the stranded mariners from the barque *Stefano* and the local Yinikurtira (West Talanjdi) Australians. The full details of this story were kept secret for over 120 years and became known only in 1990 when Gustave Rathe, the grandson of one of the only two survivors, published his book *The Wreck of the Barque Stefano off the North West Coast of Australia* (Hesperian Press). The book itself was an adaptation of the secret manuscript kept by the survivors' descendants along with a compilation of other information available on the shipwreck. The manuscript came with a map on which the alphabetical points A to Z depicted the locations where the castaways had travelled. This journey by the Stefano mariners in 1875-6 neatly overlaps today's World Heritage-listed Ningaloo coastline.

Since the publication of Rathe's book an ever-growing number of readers have become convinced that the *Stefano* shipwreck has all the hallmarks of a classic narrative. A group of these committed enthusiasts are now working with descendants of Yinikurtira Australians to have this story permanently inscribed on the Ningaloo landscape as the **Barque Stefano Yinikurtira Trail.** In 2011 a Lotterywest Trail Planning grant made it possible to fix the coordinates of the Trail locations. In 2012 the Barque Stefano Yinikurtira not-for-profit Foundation was established to oversee the establishment of the Trail.

The high point of the proposed Trail will be a chain of spectacular beach artworks leading to an Indigenous Education and Research Centre for Land and Sea Coastal Habitat in Exmouth. When the Trail is completed the Ningaloo coastline as a whole will become one large exterior art gallery hosting 21 large sculptured artworks by acclaimed Australian and international artists. Visitors will be guided to these localities by a GPS-connected Trail in cyberspace.

The aim of this Colloquium is to consolidate this Trail vision. You are invited to send in a short 150 word Abstract for a 20-30 minute presentation that can contribute to our knowledge of:

- Ningaloo Coastal Land and Marine Habitat – especially in the proximity of: Red Bluff, Gnaraloo Bay, Nine Mile Bore, Bulbarli Well, Warroora Fig Tree Well, Stevenson Well, Yalobia, Bruboodjoo, Twin Peaks, Jane Bay, Black Rock, Norwegian Bay, Lefroy Bay, Yardie Creek, Pilgonaman Well, Tulkie Well, Point Murat, Bundegi Beach, Wapet Creek, Bay of Rest, South Muiron Island.
- Ningaloo Indigenous and Heritage Sites
- Yinikurtira Country and its People
- Colonial Western Australia *circa* 1875-6
- The Stefano Shipwreck Story
- The Stefano Manuscript
- Education Potential of the Stefano Shipwreck Narrative
- The Stefano Coast: Indigenous Tourism and Knowledge Tourism
- Creative Collaboration: The Art of the Reef
- The Stefano Trail: Preserving the Ningaloo World Heritage Coast
- The Stefano Trail: Cyber Technology
- The Stefano Trail: The Spirit of the Sculptured Signage
- The Stefano Trail: Festive Tradition – 4 July
- Cultural Collaboration in the Indian Ocean
- Currents of Dreaming and Saltwater People

Please e-mail your 150 word Abstracts by 28 February 2015 to:

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Call for papers for the I. Perth Conference

NATIONAL ACADEMY OF SCREEN AND SOUND RESEARCH CENTRE

MURDOCH UNIVERSITY

IN COLLABORATION WITH DUBROVNIK UNIVERSITY

DUBROVNIK MARITIME MUSEUM

AND IN ASSOCIATION WITH THE

BARQUE STEFANO YINIKURTIRA FOUNDATION

Stefano Coast

CALL FORPAPERS
for a

Navigating along the Stefano Trail

Colloquium

2-3 September 2015
Dubrovnik University
Dubrovnik, Croatia

Please e-mail your 150 word Abstracts **for a 20-30 minute presentation**
by
23 June 2015
to

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PhD **Josko Petkovic**, Director NASS Research Centre, Murdoch University, Chair Barque Stefano Yinikurtira Foundation
And MSc **SilvijaBatos**, Dubrovnik University

COLLOQUIUM

CALL FOR PAPERS

NavigatingAlong the Stefano Trail

2-3 September 2015

In 1875,when Ningaloo coastline of Australia was still largely unexplored by Europeans,it became the setting for a most dramatic shipwreck story involving the stranded mariners from the Croatian barque*Stefano*(sailing under the Austro-Hungarian flag) and the coastal Yinikurtira Australians. Of the seventeen Stefano crew, only two survived the six-month ordeal. The two mariners who survived, Miho Bačić and IvanJurić, did so by joining a group of Yinikurtira nomads and living with them for three months until 18 April 1876 when they were picked up by Charles Tuckey in his cutter *Jessie*.

The full details of this story were kept secret for over 120 yearsand became known only in 1990 when GustaveRathe, the grandson of Miho Bačić, published his book *The Wreck of the Barque Stefano off the North West Coast of Australia* (Hesperian Press). The book itself was an adaptation of the secret manuscript completed shortly after the two shipwrecked sailors returned home to Dubrovnik and with the help of Canon StjepanSkurla. The 276-page manuscript, written in Italian, was subsequently passed on by Bačić and his family to their descendants. The manuscript came with a map on which the alphabetical points A to Z depicted the locations where the castaways had travelled with their Indigenous helpers. This journey neatly overlaps today's World Heritage-listed Ningaloo coastline.

Navigating Along the Stefano Trail Colloquium continues a longstanding collaboration between Murdoch University and Dubrovnik Universityon the Stefano shipwreck project. The primary aim of this Colloquium is to explore the contextual details of this shipwreck storywith particular focus on the navigational practices both past and present.

You are invited to send 150 words Abstract (in English or Croatian) on the following topic:

Dubrovnik *circa* 1875: Demography
- Maritime Tradition
- Dubrovnik Maritime Training
- Navigating on the High Seas: Navigation Technology
- Log Keeping Tradition on 19cMerchant Vessels

		Shipwreck Protocol and Conventions
		Maritime Emergency Provisions
		Maritime Law and Compensation Practices
		Adriatic Shipbuilding *circa* 1873-75
		Peljesac Maritime Tradition
		PontosEuxenos (Black Sea) Trade
		Maritime Oral Traditions
		Votive Traditions
Indian Ocean *circa* 1875	Indian Ocean Maritime Trade	
		Spice Route and Brouwer Route
1909 "Stefano"	1909 "Stefano":Fact and Fiction	
2015 BSY Trail:	The Stefano Manuscript	
		Data and Archive Management
		Navigating with GPS on the Stefano Coast
		Festive Tradition – 4 July Reunion
		Festive Tradition: No 1 Nuclear Target in Australia
		NWC and Montebello Interpretation Centers
		Spirit of the Signage
		World-Heritage Research and Pre-Contact Culture
		Korcula-Fremantle Charter of Friendship

Since the publication of Rathe's book an ever-growing number of readers have become convinced that the *Stefano* shipwreck has all the hallmarks of a classic narrative. A group of these committed enthusiasts are now working with descendants of Yinikurtira Australians to have this story permanently inscribed on the Ningaloo landscape as the**Barque Stefano Yinikurtira Trail.**

In 2012 the Barque Stefano Yinikurtira not-for-profit Foundation was established to oversee the establishment of the Trail.The high point of the proposed Trail will be a chain of spectacular beach artworks leading to an Indigenous Education and Research Centre for Land and Sea Coastal Habitat in Exmouth. When the Trail is completed the Ningaloo coastline as a whole will become one large exterior art gallery hosting 21 large sculptured artworks by acclaimed Australian and international artists. Visitors will be guided to these localities by a GPS-connected Trail in cyberspace.

One aim of the ***Navigating Along the Stefano Trail*** Colloquium is to contribute to this vision of the Barque Stefano Yinikurtira story.

The Colloquium program will include tours of Stefano-related Dubrovnik localities, including:

- Dubrovnik Maritime Museum
- Jesuit Church Library (once linked to)
- Miho's School in the Old Town
- Maritime School (Restaurant)
- Pile (Bacic Family environs)
- Costa Family environs
- Skurla's resting place
- (Milosrja) Church Museum
- Dubrovnik Stefano Club (model)
- Gruz

The Colloquium organizers will explore a range of other Stefano-related tours. You will be given additional information on the status of these tours with the acceptance of your paper. The following tours will be considered by the organizers:

Dubrovnik Local

- Cavtat (Epidaurus origins of Dubrovnik)
- Šipan (Stefano story – John Vincent aka VickoVukovic)
- Lokrum (Richard the Lionheart's shipwreck legend)
- Mljet (St Paul's shipwreck legend)

Dubrovnik-Kotor-Dubrovnik

- Konavle (Brajevic, mariner on Stefano)
- Perast (Venetian Naval School)
- DrazinVrt (Angelina's mother - Vukasovic)
- Orahovac (Angelina's father)

- Dobrota (Vulovic, Stefano mariner)
- Kotor (Zanetovic – Cook, Stefano)
- St Stefan (Legend of St Stefan)
- KonavonskiDvori (Dinner)

Dubrovnik-Korcula-Blato-Vela Luka

- The Walls of Ston aka "European wall of China"
- Korcula Museum
- Moreska
- Blato
- Vela Luka
- Vela Luka Cave

Korcula- Oskorusno -Korcula

- Kucisce (Dediol, Stefano)
- Church of Angels Museum
- Orebic Museum
- Oskorusno (Juric, Stefano)
- Potomje (Radovic, Stefano)
- Kuna (Skura, Stefanol)

Split-Rijeka-Trieste-Venice

- Rijeka (Osoinak, Stefano's 1st mate)
  (Pavisic, Stefano's Quartermaster)
- Mali Losin (Antoncic, the Stefano carpenter)
  (Perancic, the Stefano mariner)
- Trieste (death of Captain Stefano Baccich)
- Venice (Marko Polo, Dalmatian School)

European Tours

- Bordeaux (wine industry, Stefano's port of trade)
- Cardiff (Henry Groiss, Cabin Boy, Port of Departure, coal)

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Call for papers for the II. Dubrovnik Conference

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CALL FORPAPERS
for

The Stefano Shipwreck:
Contested Narratives and Contested Identities

11-12 September 2015
Split University
Split, Croatia

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COLLOQUIUM

CALL FOR PAPERS

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The Stefano Shipwreck:
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11-12 September 2015

The remote Australian Ningaloo Coast is one of the most impressive coastlines in the world. It contains the longest fringe coral reef in Australia and its pristine beauty is protected by a series of marine parks. In June 2011 the World Heritage Committee declared the Ningaloo Coastto be on the World Heritage List.

In 1875,when this coastline was still largely unexplored by Europeans,it became the setting for a most dramatic shipwreck story involving the stranded mariners fromthe Croatian barque*Stefano*(sailing under the Austro-Hungarian flag) and the coastalYinikurtira Australians. Of the seventeen Stefano crew, only twosurvived the six-month ordeal. The two mariners who survived, Miho Bačić and Ivan Jurić, did so by joining a group of Yinikurtira nomads and living with them for three months until 18 April 1876 when they were picked up by Charles Tuckey in his cutter *Jessie*.

The full details of this story were kept secret for over 120 yearsand became known only in 1990 when GustaveRathe, the grandson of Miho Bačić, published his book *The Wreck of the Barque Stefano off the North West Coast of Australia* (Hesperian Press). The book itself was an adaptation of the secret manuscript completed shortly after the two shipwrecked sailors returned home to Dubrovnik (*Ragusa*) and with the help of Canon StjepanSkurla.The 276-page manuscript, written in Italian,was subsequently passed on by Bačićand his familytotheir descendants. The manuscript came with a map on which the alphabetical points A to Z depicted the locations where the castaways had travelled with their Indigenous helpers. This journey neatly overlaps today's World Heritage-listed Ningaloo coastline

The Stefano shipwreck story invokes a range of contested narratives, contested languages and contested cultural and national identities. This was so for the Indigenous Australians who were subject to powerful and often harsh colonial authorities and who even presently continue to suffer various forms of discrimination. Something similar was true for the Aboriginal Europeans, namely Dalmatian-Croatians mariners on the Stefano who, after their rescue,were frequently identified as Austrians and had to officially communicate in Italian language as mandated by theImperial Austro-Hungarian government. In this contested cultural space there were costs and benefits to both groups.

One aim of the Colloquium is to explore this cross-cultural story and find out as much as is possible about the sailors on the barqueStefano and about the Aboriginal Australians who helped and cared for them. To contribute to the understanding of the story several contemporary Australian films directed by Indigenous Australians will be screened at the Split International Festival of New Film. The Colloquium is also an opportunity to search and find out any available information on the Stefano crew. The crew list includesmarinersfrom the following Adriatic localities:

DUBROVNIK	**Vlaho Miloslavić** - Captain (d.27.10.1875), presumed drowned after the second small boat launched from the Stefano overturnednear the shipwreck site (at Point Cloates) withBačić, Bučićand Osoinakin it. Miloslavić was last sighted in the water by Bučić. His body was never found.
RIJEKA	**Martin Osoinak**, First Mate(d 27.10.1875), presumed drowned after the second small boat with Bačić, Bučić and Miloslavić overturned near the shipwreck site. Last sighted in water by Bučić. His body was never found.
KOTOR	**Mato Zanetović**, Cook(d 27.10.1875), was in the last group to abandon the Stefano. Presumed to have drowned near the shipwreck site. His body was never found.
GRUŽ	**Baldasar Vukasinović**, (d 27.10.1875), was in the last group to abandon the Stefano. Presumed to have drowned near the shipwreck site. His body was never found.
RIJEKA	**Gregor Pavisić**, Quartermasters(d 27.10.1875), wasin the last group to abandon the Stefano. Presumedto have drowned near the shipwreck site. His body was never found.
POTOMJE	**Ivan Pavlo Radović**, (d. 27.10.1875), was in the last group to abandon the Stefano. His was corpse found on the beach a day after the shipwreck on 28 October around 2 miles north of the first camp (Point B)and buried where found. Grave not found.
CARDIFF, WALES	**Henry Groiss**, Cabin Boy. (d.27.10.1875) was on the first small boat when it was smashed by waves. Presumed to have drowned near the shipwreck site. His body was never found.

Two mariners lost their lives a few months after the shipwreck when the survivors were hit by the 1875 Christmas Day cyclone. These fatalities include:

DOBROTA	**Bozidar Vulović**(mariner), Died during the storm. 24.12.1875-2.1.1876Corpse discovered and buried on 2.1.1876 near Bulbarli cave and not far (50 paces) from BulbarliWell.His grave has not been found.
MALI LOŠINJ	**Josip Perančić**, Died during the story 24-26.12.1875, found 26.12.1875 and buried about ½ mile east of Warroora Beach.Grave not found.

Weakened by the storm six more mariners died in January 1876. These included:

DUBROVNIK	**Karlo Costa**, Second Captain (d. 13.1.1876). Died ina cave under the Black Moon Cliffs, Warroora. Buried in the sand near the cave some 10 paces away. Grave not found.
DUBROVNIK	**Ivan Lovrinović**, Second Mate; (d. 20/21.1.1876) buried near the Fig Tree Well, Warroora. Grave not found.
MALI LOŠINJ	**Domenik Antončić**, Ship Carpenter, (d. 23.1.1876), died near the Fig Tree Well, Warroora.Buried nearby in sand on 24.1.1876. Grave not found.
KONAVLE	**Nikola Brajević** (d.20-23.1.1876, found 23.1.1876), died on the way from Fig Tree Well to cave under the Black Moon Cliffs, Warroora. Buried in sand, 24.1.1876. Grave not found.
RIJEKA	**Fortuna Bučić**, Quartermasters, (d. 25.1.1876) died in a cave under the Black Moon Cliffs, Warroora. Not buried for 3 years. Buried in the same cave by Edwin Bush on 16 November 1879. Grave which was covered by large sea shells never found.
KUĆIŠTE	**Toma Dediol**, d 26.1.1876, in a cave under the Black Moon Cliffs, Warroora. Not buried for 3 years. Buried in the same cave by Edwin Bush on16 November 1879. Grave which was covered with large sea shells never found.

The details of the two survivors are as follows:

DUBROVNIK	**Miho Bačić,** Cadet, Pile, Moved to New Orleans, USA in 1881. Died on December 1935.
OSKORUŠNO	**Ivan Jurić**, Remained in Oskorušno, on the peninsula of Pelješac. He died in

Since the publication of Rathe's book an ever-growing number of readers have become convinced that the *Stefano* shipwreck has all the hallmarks of a classic narrative. A group of these committed enthusiasts are now working with descendants of Yinikurtira Australians to have this story permanently inscribed on the Ningaloo landscape as the**Barque Stefano Yinikurtira Trail.**

In 2012 the Barque Stefano Yinikurtira not-for-profit Foundation was established to oversee the establishment of the Trail.The high point of the proposed Trail will be a chain of spectacular beach artworks leading to an Indigenous Education and Research Centre for Land and Sea Coastal Habitat in Exmouth. When the Trail is completed the Ningaloo coastline as a whole will become one large exterior art gallery hosting 21 large sculptured artworks by acclaimed Australian and international artists. Visitors will be guided to these localities by a GPS-connected Trail in cyberspace.

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Call for papers for the III. Split Conference

4. RESEARCH METHODOLOGY

The research methodology involves qualitative scientific research, which is holistic, i.e. it seeks to present a complete picture and give meaning to the social reality that is the subject of study. It illustrates the relationship between or within the system of different cultures. Performing the analysis is the creation of interpretation, which is supported by quantitative research. The goal is not testing the theory. Researchers use an inductive model in which the theory emerges simultaneously or immediately after data collection and analysis. According to this model, researchers first collect information, then pose questions of research, shape categories, comparing theory samples and thus develop a theory or comparative models. The methodological approach of the comprehensive study of Dubrovnik's transatlantic journeys, especially to Australia, encompasses different levels, from the broadest general historical-social context to the most structured according to the type of research; from the wider maritime history through the history of Dubrovnik, to a single ship (s/s *Stefano*), from the analysis of the entire crew, to the monitoring life of one member and his family until today (Miho Bačić). This approach, the way of interpretation, reception and restitution is dealt with on concrete examples of ongoing field research, conducted by scientists in Australia. Field research will explain and verify phenomena and observations that have been analyzed by source data. In addition to field surveying, structured, deep and flat interviews are used, as well as surveys, which should confirm or deny the discovery that has been explored so far. All should be accompanied by maps, illustrations, tables and charts. The emphasis is on conducting individual research, collecting material on the selected problem, existing (archived and published), as well as new (targeted field research, case studies). Then the matter will be critically considered to form a personal preliminary opinion. The conclusion will be presented within theoretical framework. The case studies from Dubrovnik will be compared with Croatian and Australian cases collected during their field research. Qualitative, quantitative, comparative and intercultural methods will be applied to the research questions that a certain method allows.

4.1. Research draft

Once a qualitative researcher has formulated a research question, he should locate a field of research, find a number of participants and the most relevant methods for data collection. Choosing these strategies is closely related to the fact that the researcher looks at the purpose of the study, what it means, and how it understands the social and political context within which the study takes place. The most commonly used strategies are a combination of participatory observation, deep interviews, and analysis of documentation.

Table 6 Qualitative research draft

CHARACTERISTICS OF THE QUALITATIVE RESEARCH DRAFT	
1.	The qualitative draft of the research is holistic. It represents a complete picture that reflects the depth of space (perspective of the project).
2.	The draft of qualitative research illustrates the relationship between or within the culture system.
3.	It is focused on a "face-to-face" relationship between researchers and participants.
4.	It focuses on an understanding of a particular social context, and it is not necessary to make predictions about the studied social environment.
5.	Researchers require permanent and repeated presence in the field.
6.	The time spent in the data analysis should be proportional to time spent on the field.
7.	The researcher develops a fictional model of what is happening in the field.
8.	The researcher becomes an instrument of the research, i.e. one must have the ability how to observe, behave, as well as the sharp skills needed to observe and immediate face-to-face contact.
9.	The qualitative draft combines appropriate decisions with appropriate ethical issues.
10.	It is a space for describing the role of the researcher as well as a description of the researcher's own preferences and value orientations.
11.	It requires simultaneous analysis and data collection, followed by a process of generating the theory.

Source: Halmi, A. *Strategije kvalitativnih istraživanja u primijenjenim društvenim znanostima.* Jastrebarsko: Naklada Slap, 2003.

Table 7 Triangulation

TYPES OF TRIANGULATION or the application of a variety of different methods processing and data collection	
1.	Triangulation of data or the use of different data sources in research
2.	Research triangulation or the use of different profiles of researchers or evaluators
3.	Theoretical triangulation or the application of multiple paradigms and perspectives in the interpretation of an individual set of data
4.	Methodological triangulation or the application of multiple methods and techniques in studying individual problem situations
5.	This type is added by V. Janesick, which is interdisciplinary triangulation or application of more disciplinary areas in solving theoretical or practical problems

Source: Halmi, A. *Strategije kvalitativnih istraživanja u primijenjenim društvenim znanostima.* Jastrebarsko: Naklada Slap, 2003.

Triangulation should be the heuristic weapon of a researcher and it does not mean applying only three types of methods, models and perspectives of research. There are no sharp borders. As qualitative researchers use the inductive method, this means that the categories, objects and models of research are developed directly from the data itself. Categories resulting from field notes, documents, or protocols are not hypothetically placed before the data gathering phase, but the coding and categorization system is evolving during data collection.

4.2. Methods of collecting empirical material and analysis

Table 8 Methods of collecting empirical material

METHODS	
1.	Research of the archive sources
2.	Research of the Birth Books 1870-1880 and the demographic and economic situation of the Dubrovnik region
3.	Biographical method, data from Gustave Rathe's book, from interviews with him, and interviews with living family members
4.	Participatory observation by a group of researchers in Australia

Source:Halmi, A. *Strategije kvalitativnih istraživanja u primijenjenim društvenim znanostima.* Jastrebarsko: Naklada Slap, 2003.

Methods include research of historical documents (archive records, family records, media reports) and comparison, related general empirical attitudes form scientific theory. It regulates empirical data and explains social phenomena in the area of reality that is the subject of her study. Qualitative perspective, generalization of theory and data collection and analysis are two parts of the same research process. The goal here is not testing or verifying the theory. Instead, researchers use an inductive model in which the theory is generated simultaneously or immediately after data collection and analysis. According to this model, researchers first collect information, then pose questions of research, shape categories, comparing theory samples and thus develop a theory or comparative models. Performing an analysis is the creation of an interpretation. Coding is not a rigorous analytical procedure that is performed mechanically, automatically. It's a flexible procedure. The process of open, initial encryption cleans the data and identifies key categories, description of their properties and dimensions.

5. CONCLUSION

Geographically distant and isolated Australia and Oceania entered the field of world maritime discoveries long after America, Asia, India, Japan and China. Australia was unknown, not a rich country full of legends. When the image of the present world was formed, finally, one could conclude that there was a great land far in the south, appearing in literature as "Terra Australis" or "Terra Australis Incognita". By the end of 19th and the beginning of 20th century, Croatian sailors came to Australia, left their ships and settled on the Australian mainland. Croatia was under Austro-Hungarian Monarchy, and settlers would often change their names upon arrival, so the exact number of immigrants could not be followed. Until 1913, no Croatian association or society existed. However, they formed communities of the same interest, gathering around common affairs and firms, living together and maintaining links with other Croatian settlements throughout Australia. The registers mention their names, like Miho Bačić and Ivan Jurić, sailors of s/s *Stefano* because after a shipwreck in 1875 they lived and worked for a while in Perth.

The results of historical-demographic, socio-economic and cultural research in Australia and Croatia will help in highlighting major research issues related to the origin of shipwrecks, and will be presented in the three levels: 1. narrow perspective – in the local community of Dubrovnik area; 2. broader - Croatian traditional maritime culture, as a part of the Mediterranean, and the entire world (Australia); 3. further research. It is obvious that new, contemporary, multidisciplinary and interdisciplinary research is needed, not limited to the maritime history, but include some other disciplines together with the history of Dubrovnik, the history of Australia and other cultures, participated in the case. That is how the truth, full significance and scientific contribution will be achieved. The contribution will be particularly emphasized by crossing its local-national borders, and by using it in comparative studies.

REFERENCES

[1] *Annuario marittimo per l'anno 1875*, XXV. Annata, Stabilimento Letterario Artistico (Julius Ohswaldt), Trieste, 1875, tab. XCI.
[2] Barbalić, R. *Onput kad smo partili*...Rijeka: MH, 2004.

[3] Bašić, Đ. »Nakon potonuća barka *Stefano*«. *Morski magazin – Povijest pomorstva*, 2009.
[4] Batoš, S. »Prikaz događaja *Stefano*«. *Naše more* 50 (2003).
[5] Ibid. »Prvi u svijetu – novi pomorski muzej za novi milenij«. *Naše more* 51 (2004).
[6] Ibid.»European Shibboleths, Myths and Stereotypes«, talk & workshop. International Scientific Conference: Dubrovnik Media Days, II, 2006. University of Dubrovnik.
[7] Ibid; Dubčić, J. »Seamen from Dubrovnik, first Croatian Emigrants in Australia«, talk. Dubrovnik: Maritime Museum, Argosy & University of Dubrovnik, 2010.
[8] Halmi, A. *Strategije kvalitativnih istraživanja u primijenjenim društvenim znanostima.* Jastrebarsko: Naklada Slap, 2003.
[9] Ibid. *Temelji kvantitativne analize u društvenim znanostima.* Zagreb: Alinea, 1999.
[10] Henderson, G. *Unfinished Voyages – Western Australian Shipwrecks 1851-1880.* Perth: University of WA, 1988.
[11] Ibid. *Western Australians and the Sea. Our Maritime Heritage.* Perth: WA Museum, 1986.
[12] Korenčić, M. *Naselja i stanovništvo SR Hrvatske (1857-1971).* Zagreb: Djela JAZU 54, 1979.
[13] Kapetanić, N. ; Vekarić N. »Utjecaj kršćanstva na izbor osobnih imena u selima Dubrovačke Republike.« *Anali Zavoda za povijesne znanosti JAZU u Dubrovniku* 28 (1990).
[14] Luetić J. »Katastrofa barka *Stefano*« , *Pomorstvo*, X, 1-2 Rijeka (1955) 32
[15] Ibid. *Pomorci i jedrenjaci Republike Dubrovačke.* Zagreb: NZMH, 1973.
[16] Lupis-Vukić, I. *O iseljavanju našeg naroda i o Americi.* Zadar: 1910.
[17] Ibid. »Brodolom naših pomoraca iz g. 1876«, *Dubrava* IX,114 Dubrovnik, (15. II. 1941).
[18] McCarthy, M.; Henderson, G.; Batoš, S. »Insight into History: The Heritage of the Deep, Finding s/s *Stefano*«. *Naše more* 54 (2007)
[19] Muljačić, Ž. »Osobna imena u Dubrovniku (župa Grad) od 1800. do 1900. god.« *Filologija* 4 (1963).
[20] Perić, I. *Dubrovačka periodika (1848-1918*). Dubrovnik: Zavod za povijesne znanosti JAZU, 1980.
[21] Ibid. *Dubrovačko pomorstvo u 19. i 20.st.* Zagreb: JAZU, 1984.
[22] Petković, J.; Batoš, S. »Remembering Gustave Rathe«. *Naše more* 54 (2007).
[23] Rathe, G. *The Wreck of the Barque Stefano off the NW Cape.* New York: Giroux Strauss, 1992.
[24] Sala, A. *Stefano Castaways.* Mundarig WA:Warrigal Press, 2009.
[25] Suppan, A. »Narodi Habsburške Monarhije: Hrvati«. *Oblikovanje nacije u građanskoj Hrvatskoj.* Zagreb: Naprijed, 1999.
[26] Šimunović, P. *Hrvatska prezimena, podrijetlo, značenje, rasprostranjenost.* Zagreb: Golden marketing, 1995.
[27] Štuk, N. »Još nekoji podaci o brodolomu naših pomoraca iz 1875 na pustošnoj obali Australije«. *Jadranska straža* XVI,11, Split (1938), 465-466.
[28] Ibid. »Brodolom naših pomoraca iz god. 1876«. *Dubrava* IX, 113 Dubrovnik (1941, o Sv. Vlahu).
[29] Šutalo, I. *Croatians in Australia.* South Australia, Kent: Wakefield Press, 2004.
[30] Vekarić, N. ; Vranješ Šoljan, B.»Početak demografske tranzicije u Hrvatskoj«, *Početak demografske tranzicije u* Hrvatskoj, ur: Nenad Vekarić i Božena Vranješ-Šoljan. Zagreb-Dubrovnik: HAZU, 2009.
[31] Žitko, D. *Ex voto, votivne podobe pomorcev*. Koper: KK, 1992.

Sources

Matične knjige krštenih, umrlih i vjenčanih 1870.-1880.
Zavjetne slike pomoraca i natpisi u Galeriji Crkve Gospe od Milosrđa u Dubrovniku

Croatian Press

Dubrovnik, I, br. 6, Dubrovnik, 1929
Jadranska straža, XVI, br. 11, Split, 1938
Dubrava, VIII, br. 82, Dubrovnik 1940.
Dubrava, IX, br. 113, (O Svetom Vlahu), Dubrovnik, 1941
Dubrava, IX, br. 114, (15. II. 1941.), Dubrovnik, 1941
Čuvar Jadrana, IV, br.157, Split, 1951

Australian Press

The McIvor News, 22 Feb. 1861.
The Gippsland Times, 18 Oct. 1864.
Inquirer, 18. Jan. 1876.
Fremantle Herald, 23. Sept. 1876.
The Great Southern Advocate, 4. Oct.1889.
The Yackandandah Times, 13 Sept. 1890.
The Southern Mail, 18. Dec 1890.

The Korumburra Times, 12. Dec.1903.
Inquirer, 30. Oct 2006.

Online sources

http://nass.murdoch.edu.au/docs/STEFANO_EDITING.pdf
www.stefanocybertrail.com
www.lifeonperth.com

Picture 1 Votive painting *Jessie*

Source: Gallery in Capuchins Monastery & Our Lady of Mercy Church Museum, Dubrovnik

Picture 2 Pater Nikola Stanislav Novak, a guardian of Capuchins Monastery in Dubrovnik (He brought the *Jessie* painting to be exhibited in Western Australia), PhD Joško Petković and Aboriginal children during opening occasion of the New Maritime Museum in Perth

Source: Gallery in Capuchins Monastery & Our Lady of Mercy Church Museum, Dubrovnik

Dubrovnik Argosy Club gathering at Her Lady of Mercy Church Museum in 2011: (L-R) Branko Vekarić, Milo Katić, Vladimir Glavočić – president Argosy Club, Mladen Mitić, Pater Nikola Novak, Silvija Batoš – University of Dubrovnik, Mario Marčinko, Đivo Basić – Dubrovnik Maritime Museum (Photo J. Petkovic, 2011)

Picture 2 Members of the Argosy Club, Mr Milo Katić (Carlo Costa's relative) and MsC Silvija Batoš (University of Dubrovnik) with pater Nikola Stanislav Novak (Photo J. Petković, 2011)

Source: http://nass.murdoch.edu.au/docs/STEFANO_EDITING.pdf

USING ARTIFICIAL INTELLIGENCE METHODS TO DETECT THE HORIZON LINE IN MARINE IMAGES

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Summary

The information about ship spatial orientation is required by different ship systems. For example, dynamic positioning, artillery, or video tracking systems, to stabilize a ship, a gun or a camera, have to work in advance, and therefore, they need the information about future ship orientation. One method for determining the ship spatial orientation is an optical system including video cameras, a computer and specialized software. The system works through extracting the horizon line from each video shot and calculating an angle between the line and the horizontal border of the shot. The paper outlines the problem and reports experiments with different artificial intelligence methods whose goal was to detect horizon line in marine images.

Keywords: horizon, artificial intelligence, optical system

1. INTRODUCTION

Rapid development of science in the field of artificial intelligence and automation leads to numerous applications. The development is particularly noticeable in the area of unmanned vehicles. Unmanned Aerial Vehicles (UAV), (if armed - Unmanned Combat Air Vehicles, UACV), Unmanned Ground Vehicles (UGV), Unmanned Surface Vehicles (USV), Unmanned Underwater Vehicles (UUV), or collectively drones, are used nowadays at sea, on land, and in the air. In order for the contemporary drones to be able to perform their tasks, they are equipped with a sort of intelligence, what is more, the drones are becoming more autonomous. However, the intelligence itself is insufficient to achieve effective autonomous machines, to this end, the machines have to be also equipped with appropriate sensors which provide them information about external world.

Video cameras, because of their low cost, small weight and size are currently the most often used dron's sensors. Vision systems can play the role of primary sensors or can be a support of other systems, e.g. acoustic sonars. Their task is to detect different objects in video streams and provide the information about the objects to other systems. A horizon line (HL) is one of the most interesting objects that can appear in the scene and which can be used to determine position of the vehicle or its spatial orientation.

The HL is a line which is observed as a borderline between sky and the remaining part of an image (land, sea, mountains, etc.). Clearance of the line depends on weather conditions in which an image is recorded and on technical capabilities of the camera. The HL can have different shapes. In marine environment, the line is roughly straight (Figure 1 a, b, c), whereas if the land instead of the sea is in the scene, it takes more complex shapes (Figure 1 d, e, f).

In order to detect the HL, different methods and tools can be applied. In all the methods the general process of detecting the line looks very similar: first, the image is recorded, next, it is pre-processed, and finally, the HL is extracted from the image.

Image acquisition is a very important stage because, as mentioned above, weather conditions and quality of the camera strongly affect the final result of image processing. During the pre-processing stage, the originally color image is usually transformed into grayscale counterpart, noise reduction filters or sharpening ones are used, and segmentation is performed in order to extract areas of the image homogenous in terms of selected features, e.g. pixel intensity, color, texture of the area. The image after segmentation is simplified in terms of the content, unnecessary noisy elements are reduced or even eliminated, and in consequence, the image includes only information useful for the HL detection. The class of segmentation methods includes also contour techniques, among which Canny filter is used most frequently.

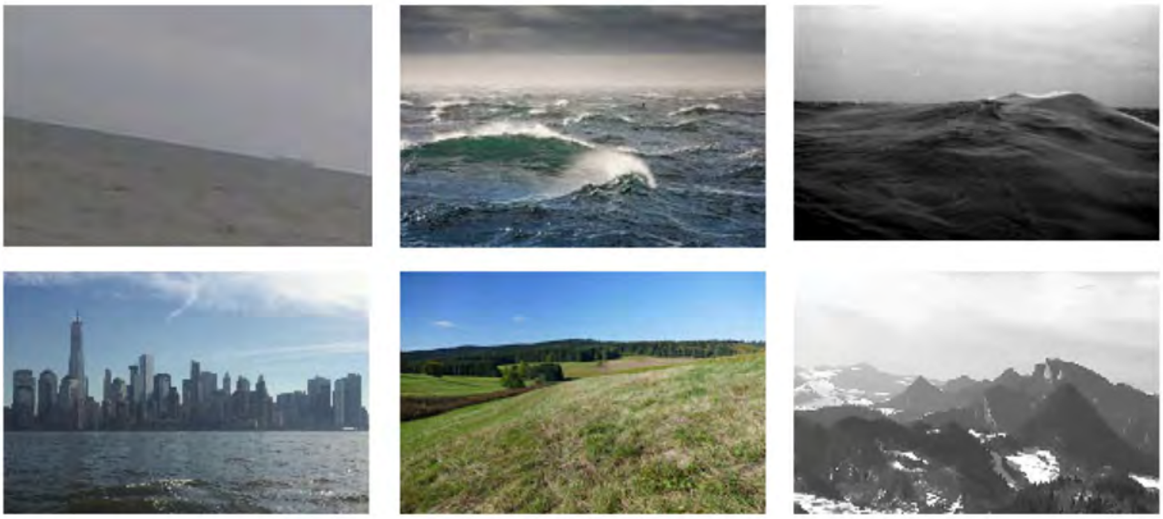


Figure 1 Images with example horizon lines

After segmentation, the process follows which describes segments with geometrical, topological, color or/and texture features. In the last phase, interpretation of the segmented image content is run with the ultimate goal to detect the HL. This phase very often looks as follows: potential lines are extracted from the image and identification algorithms are run to decide which line is the HL, if any.

A critical parameter of each HL detection system implementation is time. If the system can work without any time limitations, that is, more important is reliability of detection and line localization in the image than speed of operation, than computationally complex and very accurate algorithms are of interest. On the other hand, if the system has to work in real conditions and has to take quick decisions, "light" algorithms are needed whose high speed entails inevitably worse accuracy and reliability. The latter algorithms are preferred in different robotic systems.

When detecting the HL, it is necessary to take into account the altitude at which camera works and its resolution. In vast majority of the systems, it is assumed that the HL is straight. However, high altitude and camera resolution (see Figure 2) make curvature of the HL observable and neglecting this fact may produce errors in algorithm's calculations.

In order to detect the HL in the image, different solutions can be used [2,4]. The most well-known method is Hough transform (HT) [4,8]. It application is typically preceded by appropriate preparation of the image in pre-processing phase [3]: noise reduction, contour detection with the use of Canny, Sobel or Prewit filters. The HT is a very effective method which has been used in many different applications. The method has many variants that are described among other things in [7, 9, 13]. Implementations of the standard HT method and its several varieties are accessible for example in Python/C++ OpenCV and in Matlab.

The standard HT (SHT) is meant for detection of straight lines [11, 14, 15]. The result of SHT is a set of all straight lines visible in input image. In practical applications, more useful is the HT in PPHT version (Progressive Probabilistic HL) [12], which detects segments of straight lines. If the HL dominates in the image, that is, it is the longest straight segment, it is easy to find (see Figure 3). However, there are many cases when the HL does not dominate in the image (see Figure 4), in that case other more sophisticated procedures to find the HL have to be applied.

In the paper, the method is proposed whose task is to detect the HL in marine images, and in the instance when more than one straight segment is classified as the HL, the method tries to put them together as one straight HL. The method consists of the following elements: quick HL descriptor, supervised learning methods for straight lines classification, and linear regression for generating one HL from many lines considered as HLs.

The paper is organized as follows: section 2 outlines the field, section 3 shortly describes elements of the proposed method, section 4 gives some results of experiments on real marine images, and section 5 summarizes the paper.

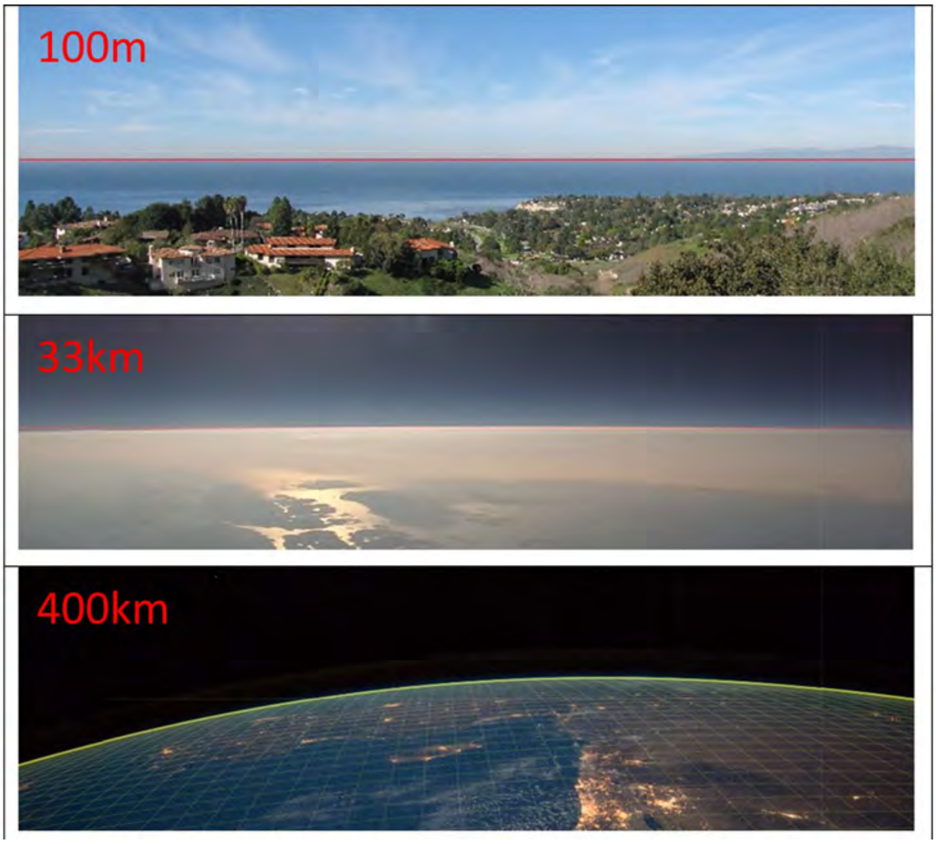


Figure 2 Curvature of the horizon line depending on the altitude

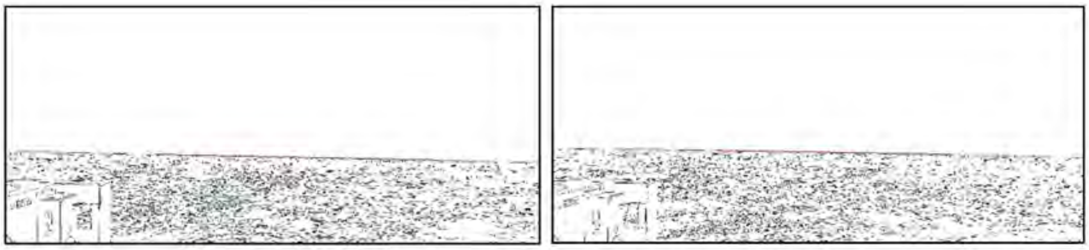


Figure 3 Straight segments detected in images (after Canny filter) by means of Hough transform – dominant horizon line is red whereas the remaining lines are green

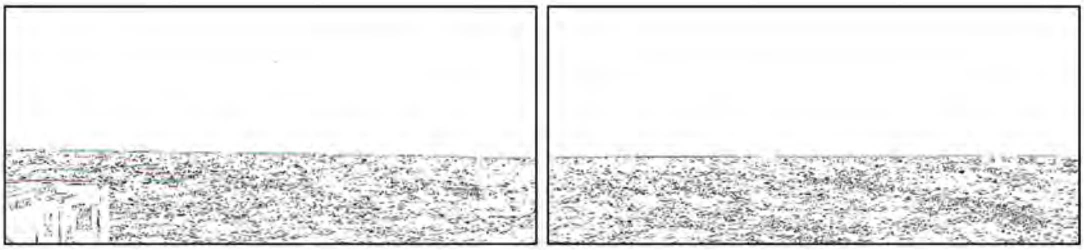


Figure 4 Straight segments detected in images (after Canny filter) by means of Hough transform – the horizon line is not dominant in these cases

2. RELATED WORK

Application of artificial intelligence methods to detect the HLs is not a new idea. The method [5] applies three types of classifiers: SVM, Naïve Bayes and J48. The verification tests of the method were performed on 10 images. One of the images was applied in the training process. To this end, the correct HL was manually marked in the image and pixels above and below the line were labelled as "Sky" or "Ground", respectively. Each pixel were characterized by 21 attributes: 3 color channels plus 6 additional texture parameters for each channel. After the training process, the method was verified on the 9 remaining images. This cycle was repeated ten times, each time with a different training image. In order to find the best HL, expectation-maximization method was applied. In the experiments, the method was correct in 90-99% of examined cases. However, for more cluttered images the results were not so promising. Due to long processing time the method is useless for the systems working in the real-time.

In work [1], advanced machine-learning and dynamic programming method for HL detection was presented. SIFT, LBP and HOG were applied to characterize image pixels. The idea of the method is to detect the most stable contours in the image (i.e. MSEE) with the use of repeated application of Canny filter with different threshold values. The number of contours MSEE that remained after Canny filtration is further reduced with SVM classifier which splits the whole set of contours into horizon and non-horizon contours. The task of dynamic programming is to produce the HL from all horizon contours.

3. METHOD

In order to detect the HL and localize it in the image, the proposed method performs five general steps:

1. Image pre-processing
2. Detection of straight lines (segments) in the image
3. Description of each line with a set of features

4. Binary classification of the lines: HL and N-HL (non-horizon lines)
5. Construction of one HL based on classified HL segments, determining parameters of the HL – optional step which is performed if the number of HL segments is > 1.

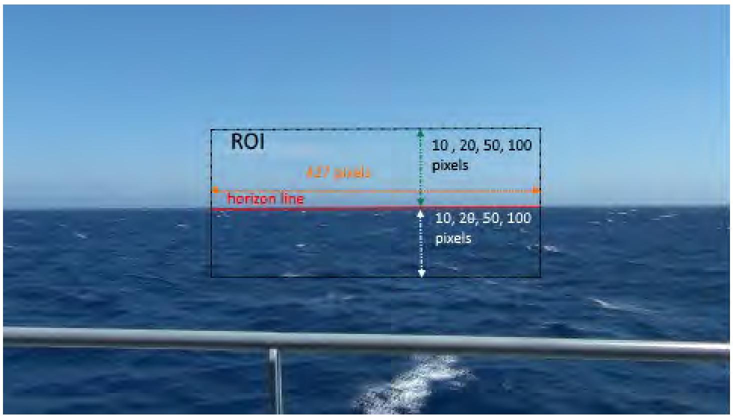
In the pre-processing step, previously tested methods of image processing are applied, i.e. converting color image into gray-scale image, averaging filter for noise reduction, and then Canny filter for contour detection. In order to detect straight lines, PPHT algorithm is applied. Values of Canny and PPHT parameters were tuned experimentally.

In order to classify detected straight segments as HL or N-HL, each segment is described with a set of features. First, for each pixel of the segment, K pixels located above (PA – pixels above) and below (PB – pixels below) the given pixel are selected (example ROI including selected pixels is depicted in Figure 5). For all PA and PB, average intensity is calculated and then difference between both averages (DA – difference of averages) is produced which ultimately represents the given pixel of the segment. If the length of the segment is L pixels, its representation has L features which means that segments of different length differ also in their representations. Because classification methods applied in step 4 need fixed length representations of each line, varied length representations are transformed to the histogram representation. The histograms has B bins and each bin in the histogram is the probability of a given DA_i (i=1..B, DAs in the histograms are evenly distributed from DA_{min} to DA_{max}) to be in a segment. To estimate probabilities for each segment, Gaussian PDF was applied:

$$\hat{f}(DA_i) = \frac{1}{L}\sum_{j=1}^{L} K\left(DA_i - DA_j\right)$$

$$K(u) = \frac{1}{\sqrt{2\pi}} exp\left(-\frac{u^2}{2\sigma^2}\right)$$

where DA_j j=1..L is DA for j-th pixel of the segment.



Data Base

pixel_nr	mean_above	mean_below	difference
1	0.450664	0.679219	0.228555
2	0.449570	0.678750	0.229180
3	0.449258	0.678555	0.229297
4	0.449492	0.678555	0.229063
5	0.449023	0.679766	0.230742
6	0.448164	0.679570	0.231406
7	0.448086	0.679141	0.231055
8	0.448828	0.679258	0.230430
9	0.448633	0.680000	0.231367
10	0.448203	0.679766	0.231563
11	0.448984	0.679453	0.230469
12	0.448633	0.679922	0.231289
....	....	......	
427	0.448555	0.680703	0.232148

Figure 5 ROI of example segment detected by PPHT

In order to classify segments represented by histogram representations of fixed length B, the proposed method uses the following solutions:

1. Support Vector Machines
2. Decision Tree
3. Discriminant Analysis
4. Logistic Regression
5. Naive Bayes
6. Nearest Neighbor

7. Ensemble Methods

The last optional step of the method is combining all HL segments in one long HL. For that purpose, linear regression is applied.

4. EXPERIMENTS

4.1. Dataset, parameter setting, course of experiment

In order to verify the proposed method and to select the most effective HL classification technique, experiments on real marine images were carried out (see Figure 6). The images, were derived from three video movies recorded on the Mediterranean Sea and Atlantic ocean. In total, 90 images were used, 30 images for each movie.

All the images were pre-processed (gray-scale transformation, averaging filter, Canny filter) and subject to HL detection with the use of the PPHT which found in the images 911 straight segments. The segments were manually labelled to HL and N-HL class, and then, for each of them 36 histogram representations were generated. Individual representations differed in K, B, and σ. The following values of the parameters were used in the experiments: K={10, 20, 50, 100}, B={10, 20, 40}, and σ={0.01, 0.05, 0.1}.

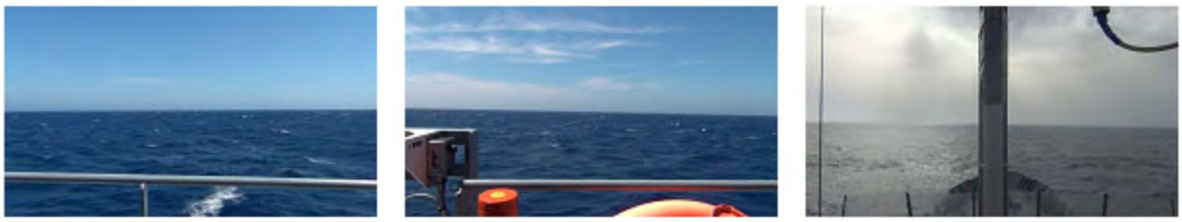


Figure 6 Example images used in the experiments

The representations of all 911 segments that were generated for the same parameter setting were divided into five disjoin sets of more or less the same size. In the further experiments, the sets were used in a role of either training set or validating set. One set filled always the role of the training set whereas the remaining four sets were used for validation purposes. To reliably measure performance of each tested classifier, each of them was trained and validated 5 times, each time with a different training and validating set.

In the experiments, 25 classifiers available in MATLAB Statistics and Machine Learning toolbox (all the classifiers represent seven classification techniques mentioned in section 3) were tested. Each classifier was trained and validated 36x5 times, each training-validation iteration differed in a form of applied representations (different K, B, σ values) and in training and validation set.

4.2. Experimental results

Results of three the most effective classification tests are presented in Table 1.

Table 1 Accuracy of individual classifiers for the three most accurate data sets

Representations	SVM	Tree	Discrim.	Regres.	Bayes	KNN	Ensemble
K=100,B=40,σ=01	98.2%	96.9%	99.1%	98.7%	97.8%	98.2%	98.7%
K=20,B=40,σ=01	98.2%	97.3%	97.8%	95.1%	98.2%	98.2%	98.2%
K=50,B=20,σ=01	97.3%	93.4%	96.9%	96.9%	94.7%	95.6%	96%

The table shows that the best results are achieved for B=40 and σ=0.1. This means that accurate histogram representations with many bins are more advantageous than rough representations with small number of bins.

When analyzing results of different classification methods, it appears that the most effective classifiers are SVN, KNN and Linear Discriminant. A detailed presentation of their results is given in Table 2. The table uses two criteria to evaluate each classifier, i.e. sensivity and specifity. Both criteria are defined below:

$$Sensitivity = \frac{TP}{TP + FN}$$

$$Specify = \frac{TN}{FP + TN}$$

where, TP is true positive (right decision), FN is false positive (wrong decision), TN is true negative (right decision), and FP is false negative (wrong decision).

Table 2 Detailed results for most effective classifiers

K=100,B=40,σ=01 – Linear Discriminant			K=20,B=40,σ=01– SVM			K=50,B=20,σ=01– SVM		
	Detected HL	Detected N-HL		Detected HL	Detected N-HL		Detected HL	Detected N-HL
True HL	TP=338	FN=5	True HL	TP=333	FN=10	True HL	TP=326	FN=17
True N-HL	FP=3	TN=565	True N-HL	FP=6	TN=562	True N-HL	FP=9	TN=559
Sensitivity= 0.985 *Specifity*= 0.995			*Sensitivity*= 0.971 *Specifity*= 0.989			*Sensitivity*= 0.95 *Specifity*= 0.984		

All the experiments were carried out on the following hardware platform:

- Intel Core i5-7200 CPU 2.7GHz / Windows 10 Pro (x64)
- 12 GB RAM
- NVIDIA GeForce 940MX.

Application of the above platform made it possible to shorten the training process to maximally 55 sec. The shortest training process took less than one second.

4.3. Linear regression

If more than one HL segment was detected, the last task of the proposed method was to generate one long HL combined with all partial lines. To this end, Linear Regression (LR) was applied. The experiments showed that the combined line after the LR is usually slightly different that original HL segments. Example result of LR application to 5 different HL segments is depicted in Figure 7.

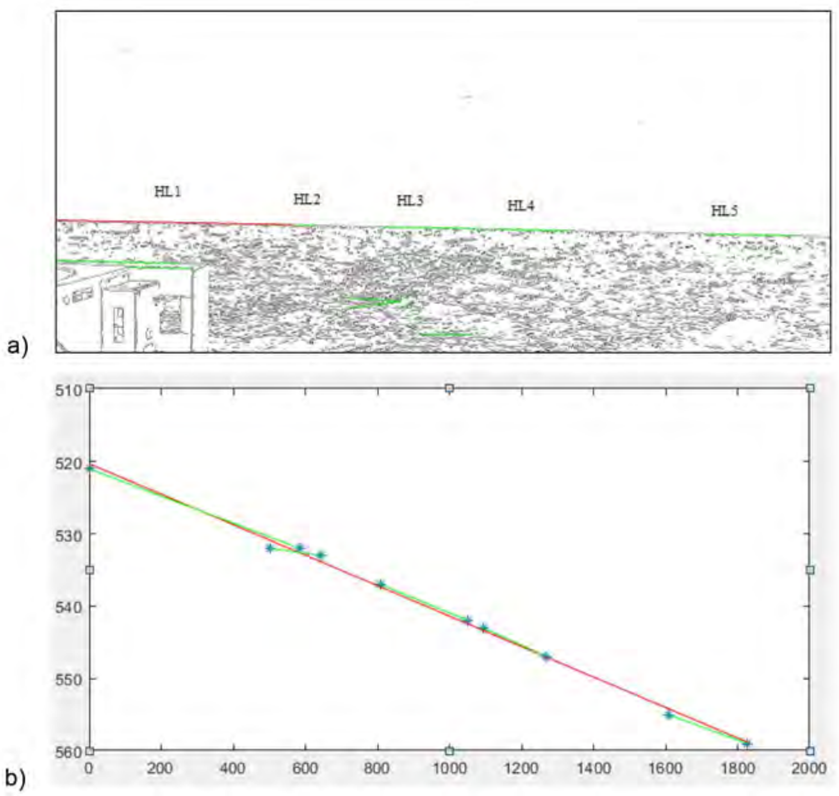


Figure 7 a) Example image with detected 5 HL segments – dominating HL is red, remaining HLs are green, b). a short fragment of resulting HL line combined with all 5 lines – red line, original partial HLs are green

5. CONCLUSION

The paper shows application of artificial intelligence methods to detect horizon lines in marine images. In order to detect the lines, the images have to be first appropriately filtered, the straight lines have to be extracted, for example by means of Hough transform, and line representations have to be generated. The line representations are fed into input of each detection method to take decision if the line is a horizon line or it is not.

To experiments reported in the paper revealed high effectiveness of the proposed approach for detecting horizon lines. It appeared that several classification methods from the field of artificial intelligence are able to almost flawlessly detect horizon lines represented in the way proposed in the paper. Accuracy of detection reached even the level of 99% of correct decisions. The result is even more impressive if the number of lines that were used in the experiments (911 lines) is taken into account.

The experiments also showed that the lines can be detected very quickly, if the classifier is already trained, the process of detection is almost immediate. High speed of presented solutions is very important for unmanned/autonomous robotic platforms that need quick algorithms for image processing in order to be able to take rapid decisions.

REFERENCES

[1] Ahmad, T.; Bebis, G.; Nicolescu, M.; Nefiany, A., Fong, T.: An Edge-less Approach to Horizon Line Detection, in 14th IEEE International Conference on Machine Learning and Application (ICMLA'15), Miami, Florida, Dec. 9-11, 2015, https://www.researchgate.net/publication/291697063

[2] Akinlar, C.; Topal, C.: EDLines: A Real-time Line Segment detector with False Detection Control. In Proceedings of the 2011 18th IEEE International Conference on Image Processing, Brussels, Belgum, 11-14 September 2011; pp. 2837-2840.
[3] Canny, J.: A Computational Approach to Edge Detection. IEEE Trans. Pattern Anal. Mach. Intell. 1986, PAMI-8 679-697.
[4] Duda, R. O.; Hart, P. E.: Use of the Hough Transformation to Detect Lines and Curves in Pictures, Comm. ACM. 15 (1972), 11-15.
[5] Fefilatyev, S.; Smarodzinava, V.; Hall, L. O., Goldgof, D. B.: Horizon Detection Using Machine Learning Techniques. In Proceedings of 5th International Conference on Machine Learning and Applications, 17-21, 2006.
[6] Grompone von Gioi, R.; Jakubowicz, J.; Morel, J-M.; Randall, G.: LSD: a Line Segment Detector, Image Processing On Line, 2 (2012), pp. 35-55. https://doi.org/10.5201/ipol.2012.gjmr-lsd
[7] Hassainen, A. S.; Mohammad, S.; Sammer, M.; Ragab, M. E.: A survey on Hough transform, theory, techniques and applications. International Journal of Computer Science Issues, IJCSI vol. 12, no. 1, January 2015.
[8] Hough, V.; Paul, C.: Method and Means for Recognazing Complex Patterns. U.S. Patent US1771560A, 18 December 1962.
[9] Kälviäjnen, H; Hirvonen, P; Xu, L.; Oja, E.: Comparisons of Probabilistic and Non-probabilistic Hough Transforms. Proceedings of 3rd European Conference on Computer Vision ECCV94, Stockholm, Sweden, pp. 351-360, May 1994. https://doi.org/10.1007/BFb0028367
[10] Lie, W.; Lin, T. C. I.; Lin, T.; Hung, K.: A robust dynamic programming algorithm to extract skyline in images for navigation. Pattern Recognation Letters, 26(2):221-230, 2005.
https://doi.org/10.1016/j.patrec.2004.08.021
[11] Liu, W.; Zhang, Z.; Li, S.; Tao, D.: Road detection by using a generalized Hough transform, Remote Sens. vol. 9, no 6, p. 590, Jun. 2017. https://doi.org/10.3390/rs9060590
[12] Matas, J.; Galambos, C. Kittler, J.: Robust Detection of Lines Using the Progresive Probabilistic Hough Transform. Comput. Vis. Image Underst. 2000, 78, 119-137. https://doi.org/10.1006/cviu.1999.0831
[13] Mudhopadhyay, P; Chaudhuri, B. B.: A survey of Hough transform. Pattern Recognit. 2015, 48, 993-1010. https://doi.org/10.1016/j.patcog.2014.08.027
[14] Tu, C.; Wyk, B. V.; Hamam, Y; Djouni, K.; Du, S.: Vehicle position monitoring using hough transform, in: IERI Procedia, 4, 2013, pp. 316-322. https://doi.org/10.1016/j.ieri.2013.11.045
[15] Vera, E.; Lucio, D.; Fernandes, L. A. F.; Velho, L.: Hough transform for real-time plane detection in depth images, Pattern Recognation Letters, vol. 103, 2018, pp. 8-15. https://doi.org/10.1016/j.patrec.2017.12.027

ADDED RESISTANCE PARAMETRIZATIONS DUE TO WAVES IN A WEATHER SHIP ROUTING SYSTEM

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Summary

This contribution compares the parametrization of the wave effect on navigation in a weather ship routing system using three different formulations. The investigation is supported by the use of a ship routing system, the SIMROUTE software, developed to obtain the optimal route and the minimum distance route through the use of pathfinding algorithms founded on high-resolution meteo-oceanographic predictions. The formulations developed by Aertssen [1], Khokhlov (suggested by Lubkovsky [17]) and Bowditch [5] have been implemented into the aforementioned software for comparing their outputs when analysing wave effect on navigation. Ship routing systems have become a key issue in recent years due to a global target focused in reducing costs and fuel emissions in Europe. In terms of time savings, the optimal ship routing analysis is investigated in a European short sea shipping system: the link between Spanish and Italian ports. As a first approach, the results show the discrepancies when using different calculation methodologies on ship routing in terms of time during energetic wave episodes. For a particular case, the rate of time savings may vary from 0.1% to more than 6% depending on the methodology applied. However, out of the three considered methods, Aertssen and Khokhlov ones give very similar results whereas Bowditch shows considerably higher values. This fact may lead to the conclusion that Bowditch approach may be too generalist to be applied to investigate the wave effect on navigation.

Keywords: Weather ship routing, wave effect on navigation, speed reduction, significant wave height

1. INTRODUCTION

Vessels speed has a pronounced effect on the fuel consumption because of the relation between the increase of speed to the exponential required propulsive power. This fact highlights the reason for being interested in lowering fuel consumption, especially when fuel prices overgrow. A major factor of competitiveness in the maritime industry is the minimization of fuel consumption and environmental protection for shipping routes. This agrees with an increase of the world tendency to reduce air emissions (energy efficiency) in the framework to mitigate the climate change effects. From the shipping industry point of view this may be achieved with an optimum route plan design. Academic research has focused the ship routing optimization through pathfinding algorithms [3, 12, 19, 21, 22, 23] which take into account the meteo-oceanographic forecasts (for example, wind, waves or currents predictions). Wave action is the major factor that affects the ship performance [13, 14, 15]. Wave field affects the ship motions decreasing the propeller thrust and adding a resistance in comparison to absence of waves. In this case, the effective speed comes by equating the propulsive forces and the resistance forces. In a still water scenario, the ship should overcome the frictional resistance because of the viscosity of the water. When the ship is sailing, the resistance increases because of the deformation of the free water surface. In this case, the added resistance is still governed by the ship hydrodynamics, but complex interactions arise between ships and both waves and currents and wind [9]. Thereafter the vessel's sailing time depends on weather conditions which are random and subject of statistical analysis. The influence of weather on ship speed can be estimated by experimental or theoretical methods. Tank tests and/or theoretical calculations are carried out to analyse the effect of waves on navigation. However, a common alternative approach is to analyse ship voyage data to predict speed loss for a given power or to find out the increase in power to maintain a particular speed. The approximate methods implemented in this study for analysing the wave effect on navigation have the advantage of relying only on key vessel characteristics such as vessel's speed in calm waters (v_0), dead weight tonnage (DWT) and vessel's length between perpendiculars (L_{BP}). These parameters serve to calculate the time saving that the vessel would attain when following the optimized route proposed by the Weather Ship Routing (WSR) software instead of following the minimum distance one under a wide range of meteorological conditions. Vessels operating on schedule often sail at designed speed and need to increase power margin up to 15 - 30% [20] to compensate for rough sea conditions in contrast to calm waters operations. The degradation of the ship performance in a seaway is accounted on the design stage for the application of a "sea margin" onto the total required engine power and a value of 15% is typically used [2]. A more accurate prediction of the added resistance with motions and ship speed loss is essential to evaluate the ship performance and environmental impact under actual weather and operating conditions. On on-going vessels, the degradation of ship performance due to hitting waves could be minimized by choosing an optimized route which would avoid high waves area as proposed in this contribution. The use of WSR can lead to the reduction of external and internal costs. On one hand, avoiding the bad weather conditions using WSR, a reduction of the fuel consumption and the mitigation of carbon emissions can be achieved. [4] introduced a calculation method into a ship routing algorithm to bring into light the impact of applying WSR on short sea shipping routes in terms of pollution mitigation using high-resolution wave numerical products. On the other hand, [11] investigates the economic benefits of using WSR on Short Sea Shipping activities, reaching the 18% of the total external costs under particular bad weather conditions in the navigation area.

The article is structured into the following sections: after the introduction (Section 1), the case study is presented in Section 2, then, the Methodology (Section 3) includes the description of the three calculation methodologies implemented into the software that will provide an optimized route in function of the ocean-meteorological conditions in short distances. The results are presented in Section 4 including the discussion (Section 5) of the assessment of the calculation methodologies to be evaluated with the proposed WSR software. Finally, the conclusions and future developments are underlined in the last section (Section 6).

2. CASE STUDY

The implementation of the optimal weather ship routing case-study using the three existing methods is investigated in a European short sea shipping system: the link between Spanish and Italian ports. The main particulars of the case-study vessel, required for the analysis, are given in Table 1.

Table 1 Case-study vessel particulars

v_0 = 16 knots	L_{BP} = 225 m	DWT = 8000 tons

Three different routes between Spain and Italy are considered in this case study, namely: (1) Barcelona and Porto Vesme route; (2) Málaga and Ajaccio route and (3) Melilla and Ajaccio route. Moreover, a wide range of different weather conditions (from calm weather to waves height up to 8 meters) during the period from November 2018 to June 2019 is also considered. Then, five different cases have been analysed applying the three methodologies (see Table 2).

Table 2 Case-study scenarios

Case No.	Wave height	Route	Date	Design speed (knots)
1	Negligible	Barcelona – Porto Vesme	12/06/2019	16.1
2	8 m	Barcelona – Porto Vesme	09/01/2019	16.1
3	5 to 8 m	Málaga – Ajaccio	23/01/2019	16.1
4	Negligible	Melilla – Ajaccio	25/11/2018	16.1
5	negligible to 8m	Melilla – Ajaccio	02/02/2019	24*

*Due to the high significant wave height, at 16.1 knots the vessel's speed would have been null

The wave predictions used are provided by Puertos del Estado and AEMET (Spanish Meteorological Agency) giving wave field forecasts and variables as significant wave height (Hs), wave direction and wave period twice a day for the Western Mediterranean Sea.

3. METHODOLOGY

This paper focuses on the assessment of three different methodologies in order to validate their appropriateness and accuracy for simulating wave effect on navigation in regular waves and various wave headings. The applied methodology consists on implementing these three existing methods into a ship weather routing system (WRS) named SIMROUTE. The pathfinding algorithms configured in this WRS are the A* Algorithm [6] and Dijkstra Algorithm [8]. Nevertheless, the one used in this contribution is A* due to computational time reduction [7]. This algorithm is applied at gridded scheme where each gridpoint (node) is connected to a set of vicinity points, as described in [10]. To each connection (edge) a weight related with the distance is assigned. The great circle (orthodromic) track is used for the spherical coordinates of the grid nodes. A* searches among all possible paths to the solution (goal) for the one that incurs the smallest cost (least distance travelled, shortest time, etc.), and among these paths it first considers the ones that appear to lead most quickly to the solution. A* is formulated in terms of weighted mesh: starting from a specific node of the mesh, it constructs a tree of paths starting from that node, expanding paths one step at a time, until one of its paths ends at the predetermined goal node. At each iteration of its main loop, A* algorithm needs to determine which of its partial paths to expand into one or more longer paths. It does so based on an estimate of the cost (total weight) still to go to the goal node. Specifically, A* selects the path that minimizes the total cost function $f(n)$:

$$f(n) = g(n) + h(n) \qquad \text{Equation 1}$$

Where:
n is the last node on the path
$g(n)$ is the cost of the path from the start node to n
$h(n)$ is a heuristic that estimates the cost of the cheapest path from n to the goal.

For the algorithm, to find the actual shortest path, the heuristic function must be admissible, meaning that it never overestimates the actual cost to get to the nearest goal node. In this case, the heuristic function is the minimum distance between origin and destination.

Before showing the results, this section presents a cursory look into the three methods implemented on the weather routing software in order to compare and find the discrepancies when using different calculation methodologies on ship routing in terms of time during energetic wave episodes. All the cases have been tested trough the algorithm and for each single case, the period of time, from the initial node to the ending node is calculated by SIMROUTE algorithm. The wave scripts (wave height and direction) have been taken from Puertos del Estado website and they have been introduced into the file.

3.1 Bowditch method

The first method implemented into the weather routing system to analyse the vessel speed reduction due to wave effect is the one proposed by Bowditch [5]. The final speed is computed in function of the non-wave affected speed (v_0) plus a reduction in function of the wave parameters:

$$v(H,\theta) = v_0 - f(\theta) * H^2 \qquad \text{Equation 2}$$

Where,
v_0 is the vessel initial speed without wave effect
H is the significant wave height
f is a parameter in function of the relative ship wave direction (see Table 3)
θ is the angle between the vessel's heading and the wave direction

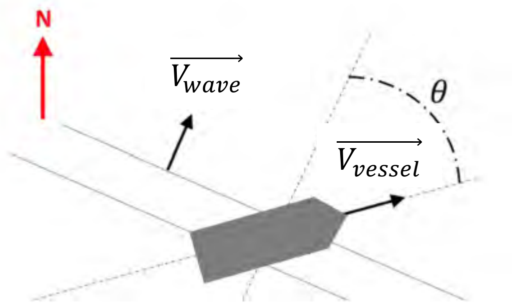


Figure 1 Definition of angle θ

Looking at Equation 2, one can see that the f coefficient has a significant impact on the speed of the vessel. The speed varies depending upon the wave height as well as the wave direction. Then, the Bowditch formula fits in the algorithm and it subtracts the speed of the vessel with the resistance of the wave in terms of height and direction. The values of f coefficient are shown in Table 3.

Table 3 Values of f coefficient

Ship-wave relative direction	Wave direction	f (in kn/ft^2)
$0° \leq \theta \leq 45°$	Following seas	0.0083
$45° < \theta < 135°$	Beam seas	0.0165
$135° \leq \theta \leq 225°$	Head seas	0.0248
$225° < \theta < 270°$	Beam seas	0.0165
$270° \leq \theta \leq 360°$	Following seas	0.0083

3.2 Aertssen method

The second methodology implemented into the WSR is Aertssen's formula [1]. Unlike Bowditch formula, this one also takes into account the ship's dimensions, in particular, the ship's length [18]. For approximating the speed reduction, Aertssen proposes the following equation:

$$v = v_0 - \left(\frac{m}{L_{BP}} + n\right)\frac{v_0}{100}$$ Equation 3

Where,
v_0 is vessel's design speed in knots and in calm waters
L_{BP} is vessel's length between perpendiculars
m and n are empirical coefficients defined in Table 4.

Table 4 Values *of m and n Aertssen coefficients depending on the wave characteristics (BN= Beaufort number, H_s=significant wave height, W_{speed}=wind speed) [20]*

		α	Head sea (150º-180º)		Bow sea (60º-150º)		Beam sea (30º-60º)		Following sea (0º-30º)	
BN	H_s	W_{speed}	m	n	m	n	m	n	m	n
5	2.5	17-21	900	2	700	2	350	1	100	0
6	4.0	22-27	1300	6	1000	5	500	3	200	1
7	5.5	28-33	2100	11	1400	8	700	5	400	2
8	7.5	34-40	3600	18	2300	12	1000	7	700	3

Source: own (data taken from [20])

The columns of the table contain estimated values of m and n coefficients for waves hitting a vessel at a particular angle. α is an angle off bow with respect to vessel's heading direction measured in degrees. The α parameter is derived by transformation of the mean wave direction (θ) estimate, defined as the mean of all the individual wave directions measured in degrees in a counterclockwise direction from the North [18].

3.3 Khokhlov method

Khokhlov formula (4) is suggested by Lubkovsky [17]. This method takes into account the height and direction of the waves and also the ship's dimensions, in particular, the deadweight of the ship. According to [18], the standard error for this formula does not exceed 0.5 knots. Khokhlov method calculates speed reduction as follows:

$$v = v_0 - (0.745 * H_s - 0.245 * \alpha * H_s) * (1.0 - 1.35 * 10^{-6} * D * v_0)$$ Equation 4

Where:
v is vessel speed in knots with the wave effect
v_0 is the vessel initial speed in knots without wave effect
α is the angle of waves off-bow in radians
D is vessel's deadweight (DWT) in tons
H_s is the significant wave height in meters

Khokhlov method is applicable for vessels with a deadweight range from 4.000 to 20.000 DWT including supply vessels, and design speeds in between 9 and 20 knots.

4. RESULTS

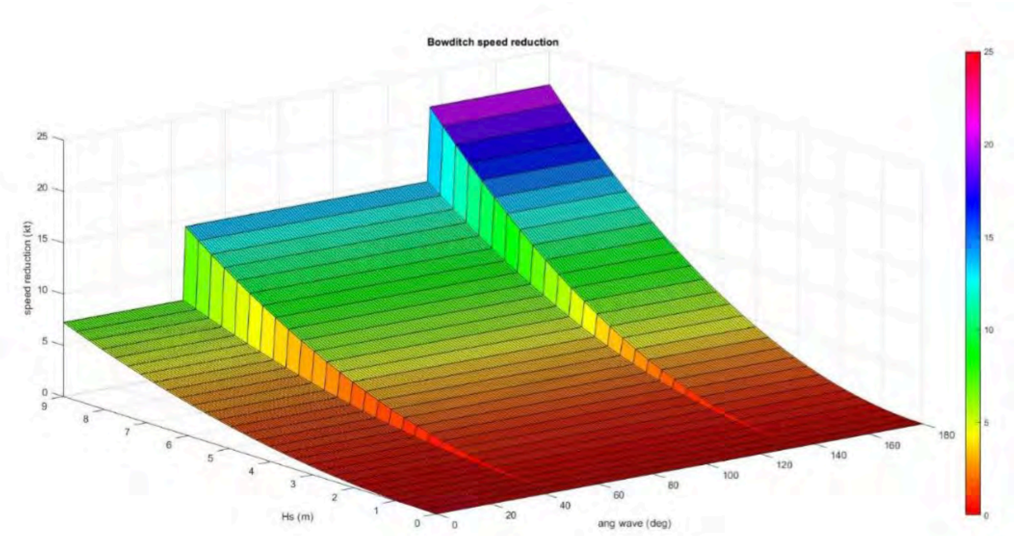
The results of this research have been obtained by implementing the three different speed loss calculation methodologies into the WSR in a particular case-study routes. The influence of wave height and wave hitting angle on the speed reduction has been compared among the three aforementioned formulations. In this section, the results of applying the three after mentioned methods are presented and intercompared.

4.1. Speed loss prediction

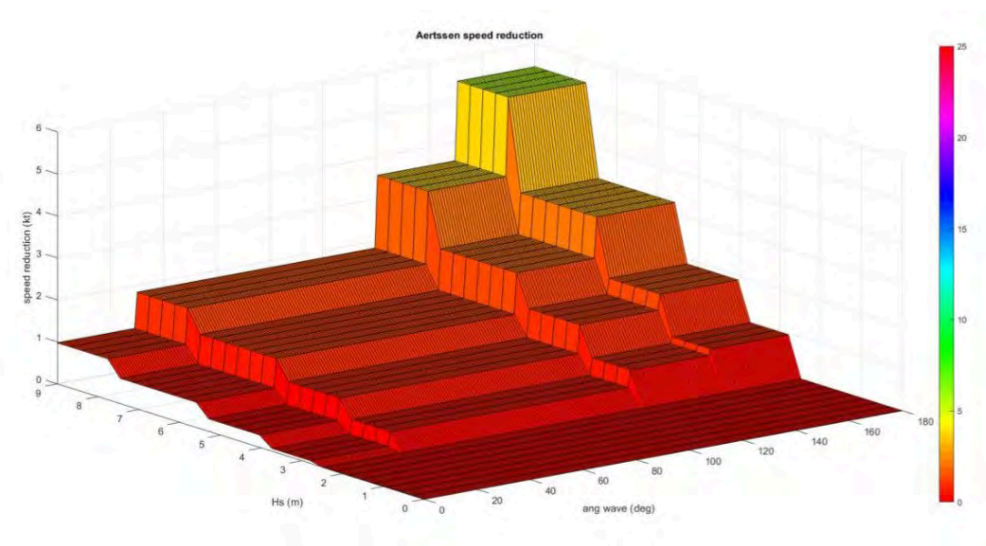
The speed loss is predicted by the proposed methodologies when the vessel faces a wide range of regular waves heights and under different wave direction conditions assuming design speed. These results will be discussed separately in section 5.

In the numerical simulations, a right-handed coordinate system x, y, z is adopted, as shown in Graphs 1, 2 and 3, where the translational displacements in the x, y and z directions are, respectively, significant wave height in meters (Hs), speed reduction in knots (v) and the ship's heading angle with respect to the incident waves in degrees (θ). For following seas, the angle θ equals 0° and for beam seas the angle equals 90°. The colour bar located at the right hand of the graphs shows the vessel's speed reduction into a range between 0 and 25 knots.

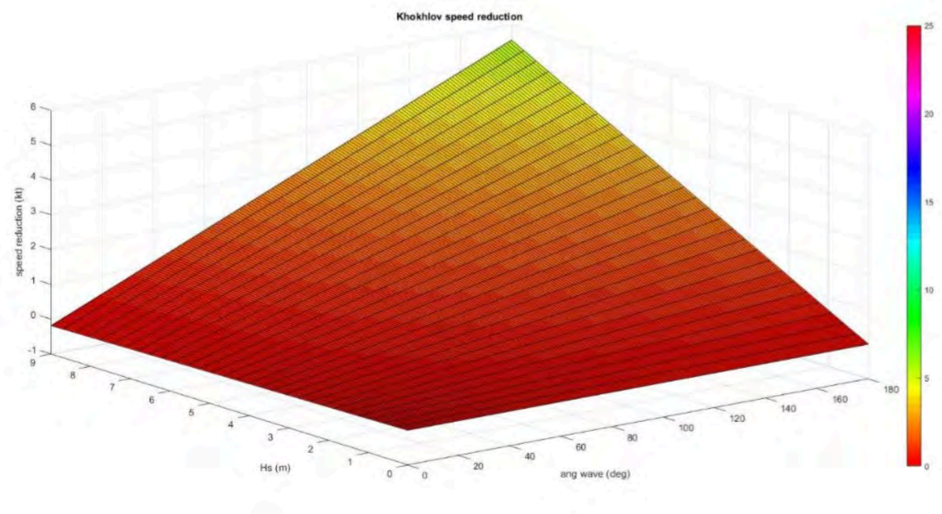
Following graphs show the speed reduction when wave height and hitting angle vary applying Bowditch method (Graph 1), Aertssen method (Graph 2) and finally, Khokhlov method (Graph 3):



Graph 1 Speed reduction related to wave height and hitting angle variation based on Bowditch formulation



Graph 2 Speed reduction related to wave height and hitting angle variation based on Aertssen formulation

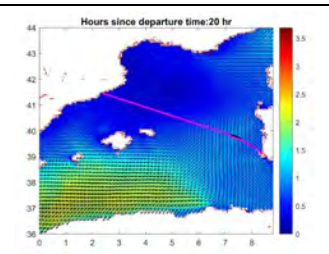
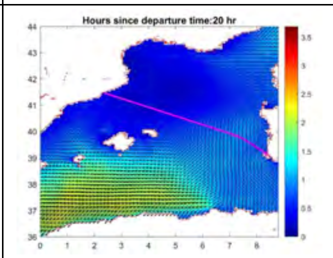
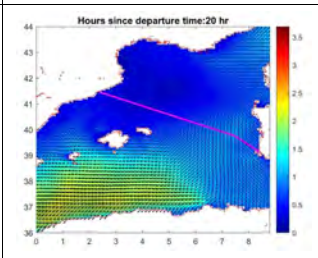
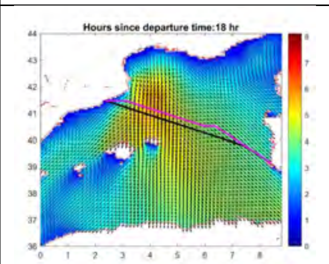
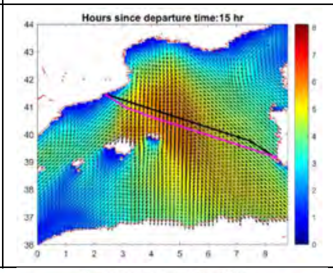
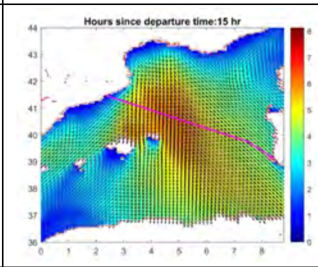
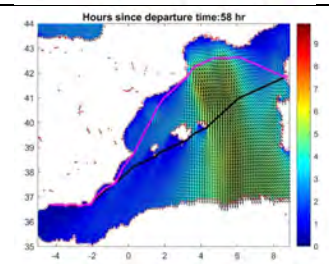
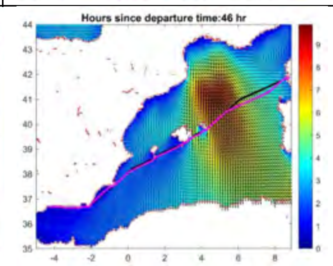
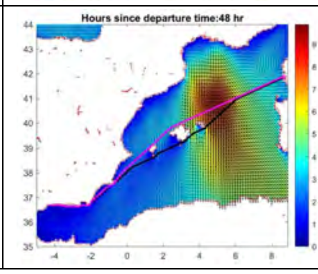


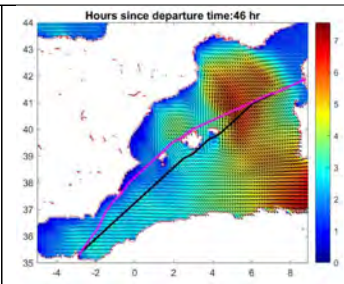
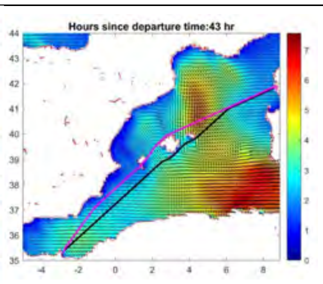
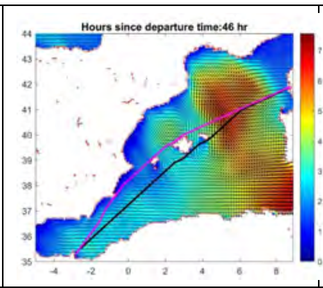
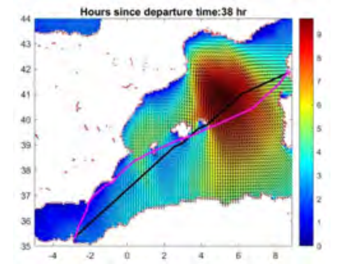
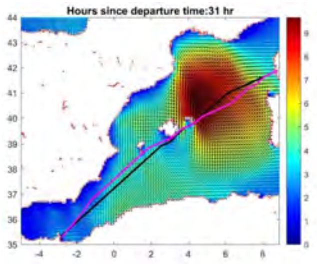
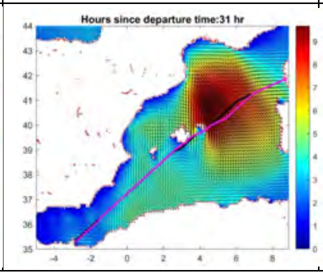
Graph 3 Speed reduction related to wave height and hitting angle variation based on Khokhlov formulation

4.2. Case-study routes results

Figure 2 shows the results of the five cases analysed where the minimum distance route is shown in black and the optimized routed proposed by the software is shown in magenta. The last column of Figure 2 shows the time saved in each case when applying Bowditch (B), Aertssen (A) or Khokhlov (K) formulation.

Figure 2 Results of the case-study routes analysed. The optimal route is plotted in magenta and the minimum distance route is plotted in black. The color bar represents the Hs (in meters) and the black arrows the propagation direction of the waves

Case no.	Bowditch (B)	Aertssen (A)	Khokhlov (K)	Time saving (%)
1				B. 0.03%
				A. 0.00%
				K. 0.00%
2				B. 0.60%
				A. 0.21%
				K. 0.00%
3				B. 3.14%
				A. 0.41%
				K. 0.15%

4				B. 2.46% A. 0.79% K. 0.96%
5				B. 6.58% A.1.12% K. 0.09%

In order to find statistical data derived from running the simulation under different routes where the vessel faced diverse weather conditions, a deeper analysis of 10 vessels' trips with different routes and duration was carried out. The mean time saving percentage when applying Bowditch, Aertssen or Khokhlov formulation is observed in Table 5.

Table 5 Mean time saving percentage

Speed reduction formulation	Time Saving
Bowditch	3.11%
Aertssen	0.65%
Khokhlov	0.29%

5. DISCUSSION

Graphs 1, 2 and 3 show the reduction of speed as function of wave characteristics, the significant wave height and the angle between the vessel's heading and the wave direction. Moreover, Aertssen and Khoklov also include some vessel's particulars as a parameter to be included in the formula. As expected, all methods analysed show the same tend, being the speed reduction of the vessel higher when the significant wave height is higher and the hitting angle comes from 180 degrees. As deducted from above graphs, Aertssen and Khokhlov formula give a similar result of a maximum speed loss of 5.5 knots whereas Bowditch formula attains almost a speed reduction of about 20 knots and reveals that Bowditch method overestimates the speed reduction.

As summarized in Figure 2, if weather conditions are adverse, the time saving increases when choosing the optimized route. Nevertheless, the results differ when applying one formulation or the other. Once again, Aerteen and Khokhlov give similar results and lower values compared with Bowditch formula.

Based on comparison results of the ship speed loss due to waves considering several sea conditions for ship operation, the capability of the developed approach to predict the ship speed loss in realistic sea conditions is unlike depending on the formulation applied. From the estimated results of the ship speed loss due to waves, at low wave height, the output optimum route is the same, however at higher wave heights, which means that the sea condition is getting more severe, the optimum route obtained from applying Bowditch method differs considerably from the other two methods considered. On the one hand, the cases analysed show that when applying Aertssen and Khokhlov formula to the algorithm A*, the results are very similar although Aertssen's time doubles Khokhlov's. However, Bowditch reduction is much more significant than the other two; by almost four times (see Table 5). The reason for this important difference is that routes calculated using Bowditch formulation avoid the zones where the vessel would face higher waves. However, Aertssen method does not consider the vessel's load and the vessel's speed loss is linked to wave height intervals instead of a concrete wave height, fact that can lead to overestimation of speed loss.

6. CONCLUSION

The parametrization of the wave effect on navigation in a weather ship routing system using different formulations, based on the inclusion of the added resistance due to the waves, evidences the relevance of wave effects on navigation and, in particular, the results reveal the influence of ship particulars and wave characteristics. The implementation of Aertssen, Khokhlov and Bowditch formulation shows discrepancies in terms of time during energetic wave episodes, being essential to use the appropriate method in each situation to obtain more realistic results. The case-study shows the rate of time savings may vary from 0.1% to more than 6% depending on the methodology applied. However, out of the three considered methods, Aertssen and Khokhlov ones give very similar results whereas Bowditch shows considerably higher values. This fact may lead to the conclusion that Bowditch approach may be too generalist to be applied to investigate the wave effect on navigation. All statements above point out in one direction, Khokhlov formulation seems to be the most realistic one because it considers the whole range of conditions avoiding an intervallic behaviour of the results. Nevertheless, Aertssen formulation would be a good choice when the L_{BP} data is available. A more accurate prediction of the added resistance with motions and ship speed loss is essential to evaluate the ship performance and environmental impact under actual weather and operating conditions.

For the sake of obtaining realistic results, further research could be carried out considering other methods for obtaining speed loss due to wave effect such as Townsin-Kwon formulae [20], which would possibly approach the results of one of the selected methodologies, facilitating the choice of the most realistic one. Kwon [16] proposed an easy approximate method to predict the involuntary speed loss in irregular waves and wind, taking into account the power output.

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REFERENCES

[1] Aertssen, G.: The effect of weather on two classes of container ship in the North Atlantic. The Naval Architect, 1975; 1:11-13.

[2] Arribas, F.: Some methods to obtain the added resistance of a ship advancing in waves, 2007, Ocean Engineering 34 (7): 946–955.

[3] Basiana, L., Castells, M., Grifoll, M., Martínez, F. X., Borén, C.: Ship-weather routing applied to short sea distances: study of the feasibility of SIMROUTEv2 algorithm, 2017, IAMU AGA 17 - 18th International Association of Maritime Universities Annual General Assembly, Varna, Bulgary: 330-340.

[4] Boren, C., Castells, M., Grifoll, M.: Intercomparison of emissions assessment methodologies in a short sea shipping framework, 2018, IAMU AGA 18 – 19th International Association of Maritime Universities Annual General Assembly, Barcelona: 416-424.

[5] Bowditch, N.: The American practical navigator, 2002, National Imagery and Mapping Agency, Bethesda, Maryland, USA.

[6] Dechter, R. and Pearl, J.: Generalized best-first search strategies and the optimality of A*, 1985, Journal of the ACM, Vol. 32, Issue 3: 505–536.

[7] Delitala, A. M. S. et al.: Weather routing in long-distance Mediterranean routes: Theoretical and Applied Climatology, 2010, Vol. 102, No. 1: 125-137. ISSN 14344483. DOI 10.1007/s00704-009-0238-2.

[8] Dijkstra, E. W.: A note on two problems in connexion with graphs, 1959, Numerische Mathematik, Vol.1: 269–271

[9] Eide, E.: Calculation of service and sea margin. Ph. D. thesis, 2015, NTNU Trondheim, Norway.
[10] Grifoll, M., Martínez de Osés, F.X.: A Ship Routing System Applied at Short Sea Distances. A: Journal of Maritime Research, 2016, Vol. XIII, No. II: 3-6.
[11] Grifoll, M., Martínez de Osés, F. X., Castells, M: Potential economic benefits of using a weather ship routing system at Short Sea Shipping, 2018, WMU Journal of Maritime Affairs. Vol.17, No. 2: 195-211. DOI: 10.1007/s13437-018-0143-6
[12] Hinnenthal, J. i Clauss, G.: Robust Pareto-optimum routing of ships utilising deterministic and ensemble weather forecasts. A: Ships and Offshore Structures, 2010, Vol. 5, No. 2: 105-114. ISSN 17445302. DOI 10.1080/17445300903210988.
[13] Hu, Q., Cai, F., Yang, C., and Shi, C.: An Algorithm for Interpolating Ship Motion Vectors, 2014, The International Journal on Marine Navigation and Safety of Sea Transportation, Vol. 8, No. 1: 35-40.
[14] James, R.W.: Application of wave forecasts to marine navigation, 1957, Report. Navy Hydrographic Office, USA.
[15] Kim, M., Hizir, O., Turan, O, Day, S., Incecik, A.: Estimation of added resistance and ship speed loss in a seaway, Ocean Engineering 141, 2017, 465-476, 0029-8018/2017. Published by Elsevier Ltd.
[16] Kwon, Y.J.: Speed loss due to added resistance in wind and waves, 2008, Naval Architect: 14-16.
[17] Lubkovsky, VK.: Determination of wind-wave speed loss of vessels for mixed type navigation with measurement of wave parameters by means of orthogonally-linear wave meters. Ph.D. thesis, Novosibirsk, 2009, VAK 05.22.19, No. 390890.
[18] Maisuik, Y., Gribkovskaia, I.: Fleet sizing for offshore supply vessels with stochastic sailing and service times, 2014, Procedia Computer Science 31: 939-948.
[19] Mannarini, G. et al.: A Prototype of Ship Routing Decision Support System for an Operational Oceanographic Service. A: TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation [on-line], 2013, Vol. 7, No. 2: 53-59. ISSN 2083-6473. DOI 10.12716/1001.07.01.06.
[20] Molland, AF., Turnock, SR., Hudson DA.: Ship resistance and propulsion: practical estimation of ship propulsive power, 2011, New York, Cambridge University Press: 57-68.
[21] Simonsen, M. H., Larsson, E., Mao, W. and Ringsberg J. W.: State-of-art within ship routing, 2015, Proceedings ASME, 34th International Conference on Ocean, Offshore and Arctic Engineering. Volume 3: Structures, Safety and Reliability. Canada
[22] Szlapczynska, J. i Smierzchalski, R.: Multicriteria optimisation in weather routing. A: Marine Navigation and Safety of Sea Transportation [on-line], 2009, Vol. 3, No. 4: 423.
[23] Takashima, K., Mezaoui, B. i Shoji, R.: On the Fuel Saving Operation for Coastal Merchant Ships using Weather Routing. A: The International Journal on Marine Navigation and Safety of Sea Transportation [on-line], 2009, Vol. 3, No. 4: 401-406. ISSN 2083-6473.

THE COMPROMISE MODEL AS A METHOD OF OPTIMIZING THE OPERATION OF NAUTICAL TOURISM PORTS

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Summary

The successful operation of a nautical tourism port can be viewed from the management's standpoint, the customer's standpoint or the standpoint of marine environment protection. The management's view focuses mainly on economic indicators, i.e. whether the revenues exceed expenses and whether there is a return on investment as envisaged by the business plan. The customer's aspect revolves around berth availability at all times, the facilities at the customer's disposal, the prices and the overall appearance of the nautical tourism port. The ever-stricter regulations on marine environment protection and the raised awareness of the same pose challenging goals before the management of a nautical tourism port that must be satisfied. The ideal situation for the management of a marina would be to have full occupancy of the berths all year round, to have the formed service price cover all fixed and variable costs, that the realized profit satisfies the owners and the shareholders and that the marina's operation has no adverse effects on the environment. The ideal situation for yacht owners would be to have a secured, ever-available berth, all accompanying facilities, an acceptable price based on the "value-for-money" principle, and secured removal and disposal of all liquid and solid waste from the yacht. The ideal situation for the environment would be to have minimal or zero reception of vessels, or a pollution-free reception if such a reception exists. Certain points of these three aspects can be observed as conflicting, because it is becoming increasingly difficult to satisfy all three aspects. Therefore, based on the compromise model of these three aspects or processes – economic indicators, customer satisfaction and marine environment protection – this paper is attempting to structure a model which would optimally demonstrate an example of successful operation of a nautical tourism port. Here, the solution presupposes finding a compromise model between stakeholders with opposing preferences. The complexity of formulating a compromise model (through optimization, or linear programming) consists of a large number of logical and numerical variables which poses limitations on the research, i.e. narrows it down to the financial component or three key variables – revenue, environmental costs and berth price.

Keywords: compromise model, nautical tourism, optimization, nautical marina, management

1. INTRODUCTION

Considering the focus on ever – more rigorous and demanding regulations on marine environment protection and coastal landscape protection and the obligations of integrated coastal management and sustainable development of nautical tourism, every new development, in an already sensitive littoral zone, is subject to rigorous checks which almost regularly and justifiably stall the development of new nautical tourism infrastructure.

It is therefore understandable that due to the increasing number of vessels sailing and permanently or occasionally staying on the East Adriatic Coast, more and more attention is paid to environmental protection as a limiting factor for the development of nautical tourism.

Accepting this reality, but also the need for developing nautical tourism as a significant industry, it is necessary to find a compromise model which would enable the enlargement of nautical capacities with the least possible threat to the environment, biological diversity and protected natural and cultural heritage.

2. LITERATURE REVIEW

The references relied upon in this research mostly derive from existing publicly available domestic sources. Due to its geographic position and configuration, Croatia is oriented towards the sea, shipping and nautical tourism. Croatia has a long tradition in shipping and tourism, a developed tourist and nautical infrastructure, as well as a satisfactory superstructure in the form of higher and academic tourist education. This resulted in abundant scientific research and published professional and scientific papers.

When considering the exploitation of maritime domain and navigation safety standards in nautical tourism ports, one must single out the research carried out by Padovan [1][1], as well as the Ordinance on the Requirements for the Arrival and Stay of Foreign Yachts and Boats Designed for Sport and Leisure in the Internal Waters and the Territorial Sea of the Republic of Croatia [2][2]. Parts of the paper relating to concessions have been paraphrased or quoted from the work of Đerđa [3][3]. Insights into nautical tourism are based on the research by Luković et al. from 2015 [4] [4] and Gračan et al. From 2015 [5][5], as well as Kovačić and Zekić [6] [6] from 2018, whose contribution consists in analyzing the comparison of capacities in nautical toursim ports of Croatia and the Northern Adriatic. For parts of the research relating to liability of the nautical tourism port arising out of the berthing contract and insurance, the author relied on the experiences of Dogan and Mršić from 2013 [7] [7] on the usability of marinas, the "Benchmarking Marina" research [8] [8].

In the presentation of general insights into the purpose and functions of an NTP, the author relied on the research by Kovačić and Luković from 2007 [9] [9], which shows the main characteristics of NTP planning and construction. The general model of nautical tourism development used in this research was established by Zelenika and Vidučić [10][10] in 2007, while in 2011 Jugović, Kovačić and Hadžić[11] [11] analyzed the sustainability of the NTP development model in the light of sustainable development of tourism. The nautical tourism market in the theory and practice of Croatia and the European part of the Mediterranean has been analyzed using the eponymous research by Luković and Gržetić [12] [12] from 2007. The relationship between a marina and charter companies from the legal aspect has been explained according to the research by Pjaca from 2018 [13] [13].

The issues regarding the protection of marine environment are mostly regulated by the International Convention for the Prevention of Pollution from Ships (MARPOL), the Environmental Protection Act and the Regulation on the Protection of Marine Environment in the Ecological and Fisheries Protection Zone in Croatia, as well as other ordinances relied upon in the research to create positions and arguments for upgrading the knowledge on the importance of environment preservation. The main idea behind the research is in line with the Strategy of Nautical Tourism Development in Croatia for the period from 2009 to 2019 (2008) [14] [14] and the Development of Ecotourism by Klarić [15] [15] (2002). The notion of costs, their analysis and effects on the business operations of a nautical tourism port have been described in detail by Peršić [16] [16], whose theses have been quoted and paraphrased in the paper.

The data on ecological incidents relevant to the research have been extrapolated from county reports. In the consideration of coastal zone management and sustainable development, the author relied on the positions taken by Kovačić and Komadina [16][16] in 2011, as well as the study by the Ruđer Bošković institute on the nautical tourism port's impact on the environment [17] [17] from 2008 and the research on the factors of harmful effects of cruising tourism on the maritime environment carried out in 2011 by Šantić, Vilke and Grubišić [19]. [19].

3. NAUTICAL TOURISM PORTS IN GENERAL

Nautical tourism ports – hereinafter NTPs, are regulated by the Maritime Code [20], the Maritime Domain and Seaports Act [21], as well as various subordinate legislation regulating the types and categories of ports, minimal requirements for such ports, as well as the categorization of ports and vessels in nautical tourism. An NTP is primarily intended for berthing and accommodation of vessels of nautical tourism and it is properly equipped to provide services to customers and vessels. Pursuant to the Ordinance on Classification and Categorization of the Nautical Tourism Ports [22], an NTP represents a business, construction and functional whole in which a legal or natural entity conducts its business and provides tourist services in nautical tourism, as well as other services serving tourist consumption (commerce, hospitality, etc.).

In NTPs, special attention is paid to safety of navigation, marine environment protection and security of the marina. The Ministry of the Sea, Transport and Infrastructure, via the directly competent Harbormasters' Office, is authorized to supervise safety of sailing and environmental protection in marinas, being a part of maritime domain and internal waters. Security in most marinas is achieved through video surveillance and an organized mariner security service, and many marinas outsource to private security agencies.

The degree of safety of navigation, marine environment protection and security in a marina is also supported through the system of insurance against potential damage. The functioning of a marina can hardly be imagined without quality insurance of the marina against various risks, primarily liability insurance of the marina concessionaire towards berth users or third parties [1].

The general issue which reflects upon the state of the maritime environment can also be found in the fact that vessels, such as sailboats and boats, are exempt from applying the MARPOL Annex IV due to their tonnage and the number of persons they are certified to carry, even though some of them are under 12 meters in length and still fall within a category which enables them to sail in international waters.

Yachts and boats built for longer navigation are equipped with limited capacity sewage holding tanks which have to be discharged occasionally. More often than not, these tanks are discharged into the sea, and mainly closer to the coast than MARPOL allows, as MARPOL does not apply to these vessels (pursuant to MARPOL, this distance for untreated sewage is 12 Nm or more from the nearest land). On the other hand, there is still a shortage of land reception stations for sewage from vessels (either in number or frequency) built in marinas, berths and quays for boats and yachts.

During the summer, in countries with developed nautical tourism such as Croatia the total number of persons on board yachts and boats exceeds by far the total number of persons on board all merchant ships in the same coastal zone. Therefore, this results in a far greater burden and pollution of the sea with sewage from vessels exempt from application of MARPOL Annex IV, as opposed to vessels falling within the scope of application of MARPOL Annex IV.

The Croatian Adriatic coast is a destination for nautical, sports and recreational tourism (seasonal sunbathing). Being a shallower and semi – enclosed sea, the Adriatic is particularly vulnerable and susceptible to pollution. Untreated waste waters mainly from inland sources and vessels aggravate this situation further [23]. Discharging sewage in internal waters and bays harms both tourism and tourists. This danger is more imminent with vessels such as yachts, boats and fishing boats which are exempt from application of legislation at the EU and MARPOL Annex IV level.

3.1. Management of Nautical Tourism Ports

Apart from entailing standard issues related to management and decision – making, management of nautical tourism ports is specific for at least three reasons. First, the development of basic services is limited by spatial capacities. Second, there is a prominent seasonal character of the services which is difficult to extend in duration due to the specificities in the use of boats. Third, the NTPs are located in the environment of an extremely ecologically sensitive coastal zone.

Regarding the environment, one must also mention the significant influence of the local community which is, as a rule, divided between commercial and ecological interests.

Apart from the above, there is also the issue of compensation of damage from pollution incurred in the NTP due to a fire or sinking caused by fuel in the vessels. The sole determination and compensation of actual damage caused by pollution is carried out according to general rules on obligations and is not difficult in itself. However, pollution of the marine environment can reflect on numerous businesses which are directly or indirectly linked to the sea, which then also gives rise to damage in the sense of loss of profit.

Responding to the above issues constitutes a compromise which necessarily means that not all wishes can be satisfied. Any imposition of unilateral solutions will inevitably lead to confrontations which sometimes surpass the limits of socially responsible business. The following table presents the frequency (F) of vessels served in the NTP (land and sea) and capacity utilization (CU) for the period between 2014 and 2017 per county.

Table 1 The number of vessels and NTP capacity utilization for the period between 2014 and 2017

	2014		2015		2016		2017	
	F	CU	F	CU	F	CU	F	CU
Republic of Croatia	13,793	61.04%	13,399	59.67%	13,422	60.17%	13,433	61.97%
Istarska	2,888	65.53%	2,807	63.75%	2,835	66.49%	2,634	69.39%
Primorsko-goranska	3,117	59.66%	2,848	57.90%	2,561	58.48%	2,648	62.04%
Zadarska	2,961	64.69%	2,877	60.43%	2,710	55.91%	2,804	56.29%
Šibensko-kninska	2,783	61.82%	2,656	57.99%	2,788	60.33%	2,835	63.11%
Splitsko-dalmatinska	1,588	53.56%	1,755	61.73%	1,950	63.85%	1,928	64.12%
Dubrovačko-neretvanska	456	49.57%	456	48.00%	578	50.57%	584	51.54%

Source: Croatian Bureau of Statistics

The data shown in Table 1 represent standard statistic indicators which point to stagnation or declining trends and relatively poor utilization. The reasons for this can be found in obsolete monitoring methodology, i.e. not updating berth capacities. Namely, the structure of vessels coming to NTPs has changed during the last decade. The vessels have gotten bigger and therefore wider (they take up more space), there are more multihulls (catamarans), the number and capacity of anchorages have increased, etc. Therefore it is more acceptable to analyze an NTP according to realized profit, considering that tariffs are mainly not subject to change.

3.2.Pollution Risks in an NTP

Preservation of the environment with rational utilization of natural resources represents one of the most relevant issues in further technological and economic growth of any country. Construction of NTPs and accompanying infrastructure lacking in control and vision often leads to total loss and depreciation of the aesthetic value of the landscape.

Table 2 Nautical tourism impact on marine environment

SOURCES OF POLLUTION IN AN NTP	MEASURES FOR PREVENTING POLLUTION OF THE MARINE ECOSYSTEM IN AN NTP
• waste water originated during the washing of vessels; • paint used to paint vessels; • waste waters originated in the washing of the engine during repairs and waste waters from washing underwater surfaces; • oily rainwater from asphalt – covered handling zones, zones for vessel and vehicle storage and internal roads; • sewage and ballast water; • mineral oils from vessels; • polyester resin particles originating from works on plastic parts of the vessel; • biocides contained in anti – fouling paints, during the vessel's stay in the marina.	• sustainable use and management of marine resources; • increase of berthing capacities through restoration, reconstruction and revitalization of existing nautical tourism ports to enable berthing of large yachts; • setting up a system for surveillance and management of navigation; • control and equipping of boats and yachts and nautical tourism ports with devices and equipment for protection of the sea from pollution; • application of new ecological standards.

Source: Author's processing according to [7][7].

As a rule, nautical tourism is not a great polluter if the infrastructure has been done according to appropriate technical standards [7]. The solution lies in avoiding high concentrations of nautical tourism ports in the coastal zone because the pollution of the sea is harder to control. It should be noted that in the construction of marinas, caution is required in the use of coastal space. Thus, in ecologically sensitive and extremely valuable zones commercial construction should be limited.

Therefore, coastal zones should be managed applying the principles of environmental ecology, as the cornerstone of the environment as a whole. This means that we must establish development priorities where marine environment protection comes first, while the development of nautical tourism ports and marinas must be in line with fundamental ecological criteria [7].

3.3. Structure of the NTP's Primary Business Activity

During the year, back to back services are provided in two basic types of NTPs – a) marinas and b) dry dock marinas. Accordingly, an NTP provides two basic types of services: a) berthing and accommodation of boats and b) lifting, transport and storage of boats.

It is assumed that each vessel of nautical tourism entering the marina for berthing or dry docking somehow pollutes the environment. The owner of the marina bears the costs incurred by documented pollution which it then charges to the owner (master) of the vessel. It is clear that the owner of the marina is insured against pollution from vessels within the marina (both sea and land), so one of the costs incurred by pollution are premiums paid for insurance against the risk of pollution. The second part of costs includes possible environmental levies imposed by the local community, costs of supervising the seabed, sea surface and dry dock, costs of waste separation and management, collection of oily liquids…

The third part pertains to training costs for marina personnel, promotional materials for customers, sea quality measurements in the marina, air quality measurements, etc.

Certainly, the simplest way is to calculate these costs in the service price, which would increase revenues but would still reflect on the profits.

3.4. Revenues from Primary Business Activity

In this paper, the author will go on to show the dynamic of revenues from primary NTP services based on research [7] on a sample of 32 NTPs (a sample representing 43.84% of NTPs and 12,345 berths, which represents 70.86% of total marina capacity in Croatia) and an approximation of investment into environmental protection by NTP management, duly noting that any investment into environmental protection represents a cost from the NTP management's standpoint.

An NTP's revenue from primary business activity is determined by the number of boats whose value is formed as meter/day. Given that boats are divided in seven categories according to length (up to 6 m, 6-8 m, 8-10 m, 10-12 m, 12-15 m, 5-20 m and over 20 m), the daily berthing tariffs are formed according to said groups as shown in the below table.

Table 2 Revenue from primary business activity

Length over all [m]	Number of boats in 2017	NTP's berth capacity	Daily wet berth (€)	Environmental unit cost (3%)	Total revenue for 2017	Projected environmental costs for 2017
up to 6 m	138	656	90	2.7	5,520	373
6-8 m	692	1,224	100	3	34,600	2,076
8-10 m	1,648	2,756	120	3.6	98,880	5,933
10-12 m	3,358	4,283	150	4.5	268,640	15,111
12-15 m	3,969	4,773	160	4.8	396,900	19,051
15-20 m	1,404	2,650	180	5.4	210,600	7,582
over 20 m	432	725	200	6	86,400	2,592

*tariffs are approximated and presented in €

Here it's worth noting that, for reasons of simplification, the author used the average tariffs for the daily, monthly and annual berth broken down to the daily berth value. This approach resulted in obtaining relevant data consistent with actual data.

The table shows that the CU is lowest with boats of up to 6 m (21%), followed by the 15-20 m category (53%), 6-8 m category (57%) and + 20 m (60%). The highest CU is achieved with boats in the 10 – 12 m category (78%) and the 12 – 15 category (83%).

The causes of such a distribution can be found in the increasing number of anchorages that meet the needs of small boats whose owners are confident of their seafaring skills and large yachts which are self – sufficient and independent of the berth in the NTP. The CU of berths in 2017 amounted to 68.2%, equal to revenue utilization (68.2%).

According to relevant indicators from financial reports published by NTP managements, the environmental protection costs in the Croatian part of the Adriatic (which is not shown as such, but extrapolated per item from the overall costs) range between 2.8% and 3.4% of total revenue.

Such cost margin is mainly acceptable to NTP managements and they calculate them in their plans and development strategies. The thing that is impossible to plan, but can be foreseen and estimated is the risk of possible pollution on a larger scale, when the consequential cost and damage to the environment can seriously jeopardize the NTP's business. The below combined chart shows revenues and environmental costs.

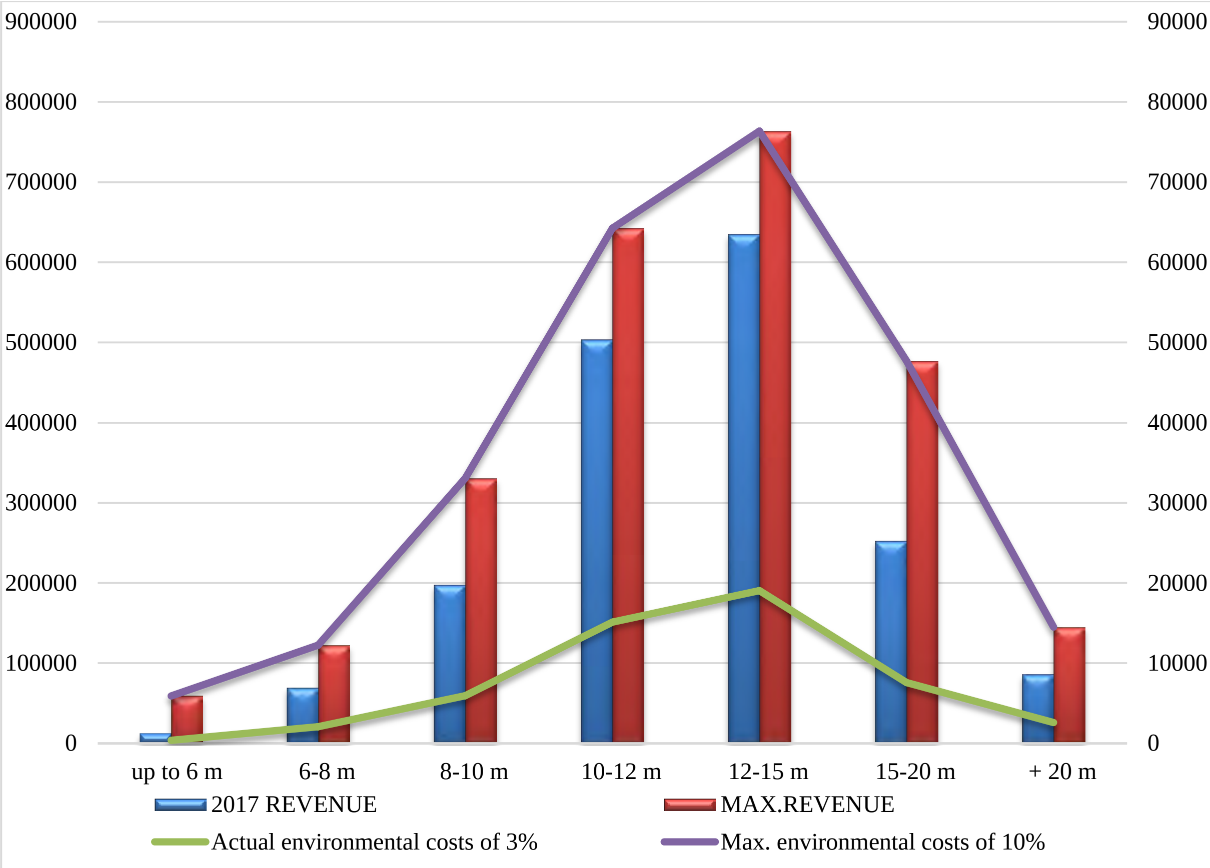


Image 1 Distribution of revenues per vessel (the left axis of the chart) and the approximation of environmental costs (the right axis of the chart)

The combined chart shows the distribution of revenues per vessel (the left axis of the chart) and environmental costs (the right axis of the chart). Considering that the environmental costs are serving the CU, their correlation is clear. It also shows the normal distribution (Gauss) which characterizes the number of meter/days and thus the revenues realized according to vessel length.

4. ENVIRONMENT PROTECTION COSTS

There are several approaches to resolving the environmental protection problem, from education to prevention and the like. As a rule, these approaches are effective, but practice shows they are insufficient. Namely, nautical tourists nowadays are not exclusively ecologically aware sea and environment enthusiasts. Any pollution poses a significant cost before the management of an NTP which will have an impact on business results. Therefore, the author will attempt to analyze the notion and approach to environmental costs as an additional contribution to environment preservation.

Environmental costs (eco costs) are conditional upon the nature of a business activity, the approach in creating the range of services, the selection of the technological process and the equipment used to achieve the goal of sustainable development, taking into account the systemic reduction of negative impact on the environment, which has to be balanced with the goal of a profitable business. [16].

Environmental costs should be analyzed as process costs which start at the design phase of the NTP and end after the breakdown of the last piece of waste long after the NTP's life span.

Environmental costs are a complex category and not always easily identifiable. We always start with conventional environmental costs, i.e. those cost positions which ae easily identifiable and connectable to activities within the NTPs aimed at the improvement and protection of the environment, such as capital costs connected with the eco-investment, the costs of eco-acceptable current and fixed assets, increased duties for improving the state in a tourist destination (green tax, increased tourist tax, …), depreciation costs, maintenance and use of joint facilities at the level of the destination (e.g. management and treatment of waste water, waste oil, garbage incinerator, compost, settlement pond, etc.).

Environmental costs are connected with the product and the process, but also with the conditions in which the service is provided, observed through the tasks and assignments which must be directed at decreasing costs and increasing revenues, systemically improving the relation towards the environment. However, environmental costs are not always easy to identify because some are only partially a consequence of actions concerning the environment, some are a consequence of past events, and some will only possibly be incurred, as is shown in the below table.

Table 4 Theoretical starting points for the classification of environmental costs

<table>
<tr><td colspan="3">CONVENTIONAL COSTS
(costs of capital, assets, materials, stock, utilities, investments…)</td></tr>
<tr><td colspan="3">POTENTIALLY HIDDEN COSTS</td></tr>
<tr><td rowspan="2">Standard (planning, training, examination, information, targeted supervision, testing, modelling, correcting, noting, marking, insurance, taxes, remuneration to target management…)</td><td>Anticipatory (R&D, licenses, examinations, location preparation, permits, engineering…)</td><td>Consequential (stopping or closing, destroying equipment, protecting the location…)</td></tr>
<tr><td colspan="2">Voluntary (feasibility studies, recycling, protection, community relations, testing…) (</td></tr>
<tr><td colspan="3">UNFORESEEABLE COSTS</td></tr>
<tr><td colspan="3">Costs of adjusting to future requirements; Penalization; Fines; Liability for future damages; Improvement measures; Potential damage to national resources, from loss of property to reduction of personal rights, etc.; Legal charges…</td></tr>
<tr><td colspan="3">Image costs and costs of relations with interest groups</td></tr>
<tr><td colspan="3">Corporate image creation costs; Costs of relations with buyers, investors, insurers, managing structures, employees, suppliers, lenders, the community, the legislature…</td></tr>
</table>

Source: Peršić and Janković, Management Accounting of Hotels, 2006

A part of the costs will be incurred if regular investments are made into environmental protection and improvement, and another part if such actions are ignored, so that there are consequences if global trends are not followed.

As stated by Peršić [16], environmental costs can be observed as (a) positive costs and (b) negative costs, as is shown in the below table.

Table 5 Types of environmental costs

POSITIVE ENVIRONMENTAL COSTS	NEGATIVE ENVIRONMENTAL COSTS
Investments are observed from the starting point of their contribution: • Raising the market image (potential for future demand) • Reorientation of business systems to new target groups (higher financial solvency); • Customer satisfaction through a higher ecological level and a better eco-offer quality (additional revenues – higher sales prices)	Not observing the ecological rules normally leads to a decrease in the profit of business systems: • Because in the modern, eco-aware market it is damaging to the image, which causes a decrease in demand and thus a systemic decrease of sale prices; • Consumer dissatisfaction because of the low standard of cleanliness, landscaping, eco-diet, etc. which leads to reclamations, returns, damages and consequently to increased (poor)quality costs; • Taking no action to systemically reduce costs of energy, water supply and waste management increases this item in the cost structure.

Source: Peršić and Janković, Management Accounting of Hotels, 2006

Costs reflect the impact of certain business activities on the possible cost structure, which is different in any business organization. In accordance with the research topic, below is an overview of synthesized environmental costs in ACI as an example.

Table 6 Recapitulation of environment – related costs in 2017

ACTIVITY	AMOUNT
Management of municipal and non-hazardous waste	2,266,040
Management of hazardous waste	394,929
Waste water analyses (Institute of Public Health)	102,332
Charges to Hrvatske vode	1,610,763
Construction, reconstruction and servicing of waste water treatment facilities	303,480
Monitoring and optimization of energy consumption	697,430
Water tightness testing	271,521
Blue flag - membership	60,000
Total 2017	5,706,496
Total costs	176,128,230
Share in total costs	**3.24%**
Total revenue	201,136,579.56
Share in total revenue	**2.84%**

Source: Author's processing according to ACI d.d. data

The example shown in table 6 demonstrates how the environmental costs influence the NTP's business. Costs recorded as environmental costs have been extrapolated from the balance sheet as unequivocal, but as such, they are incorporated into many other costs (fuel, electricity, water supply, charges…), and thus, they are valued as minimal environmental costs. As such, they participate in total costs in the range between 2.7 and 3.2%.

By simulating the increase of environmental costs, provided the revenue and other costs remain a constant, the NTP's business would come into question if the recorded environmental costs would reach 10% of total revenue.

5. COMPROMISE MODEL

The optimization methods enable the finding of the best solutions to various types of problems and are very well suited for solving problems in business economics. Typical business problems are related to the use of limited resources, but also consequential costs which are ever more significant and exactly proportionate with the raised awareness on protecting the environment. The goal is to find the appropriate model to adequately resolve the issue of environmental protection requirements and the management's interest to maximize profit.

5.1. Linear Optimization of the Compromise Problem

The most frequently used methods in business economics are methods of linear optimization which enable the finding of the most favorable solutions where both the objective function (revenue) and the resource consumption (costs) are linearly proportional to values of independent variables (the number of services produced).

It is necessary to formulate a model for linear programming, emphasizing that building the model is up to the user, while the calculation of the optimal solution and sensitivity analysis of the model is carried out by the program by using the appropriate algorithms. Result interpretation is again up to the user. The problem of linear programming therefore leads to the optimization of the value of a linear function of decision-making variables, satisfying a certain number of linear consraints expressed in the form of inequations. The function being maximized is called the objective function, and the coefficients within the constraints are called technological coefficients.

The optimization is carried out using the LINDO (Linear Interactive and Discrete Optimizer) computer program.

A model with two inequations is created, specifically:

1) The MAX, which uses indicators from Table 3 to search for optimal values for the maximum CU. Constraints posed before the first inequation (SUBJECT TO) are the ranges between values observed in 2017 and those maximum possible valuesconsidering the capacity of individual variables, and the second inequation
2) The MIN, which searches for optimal values of environment costs – EC. The constraints for this inequation have been created in a way that EC are determined for each individual variable in the range between the observed (EC in 2017) and the maximum EC acceptable (the presumed 10% of TR).

As shown in Figure 2

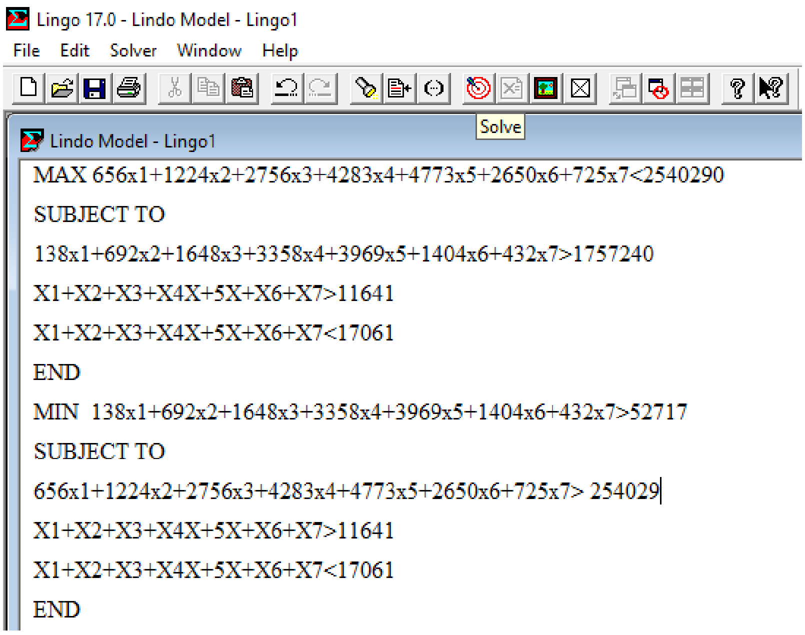
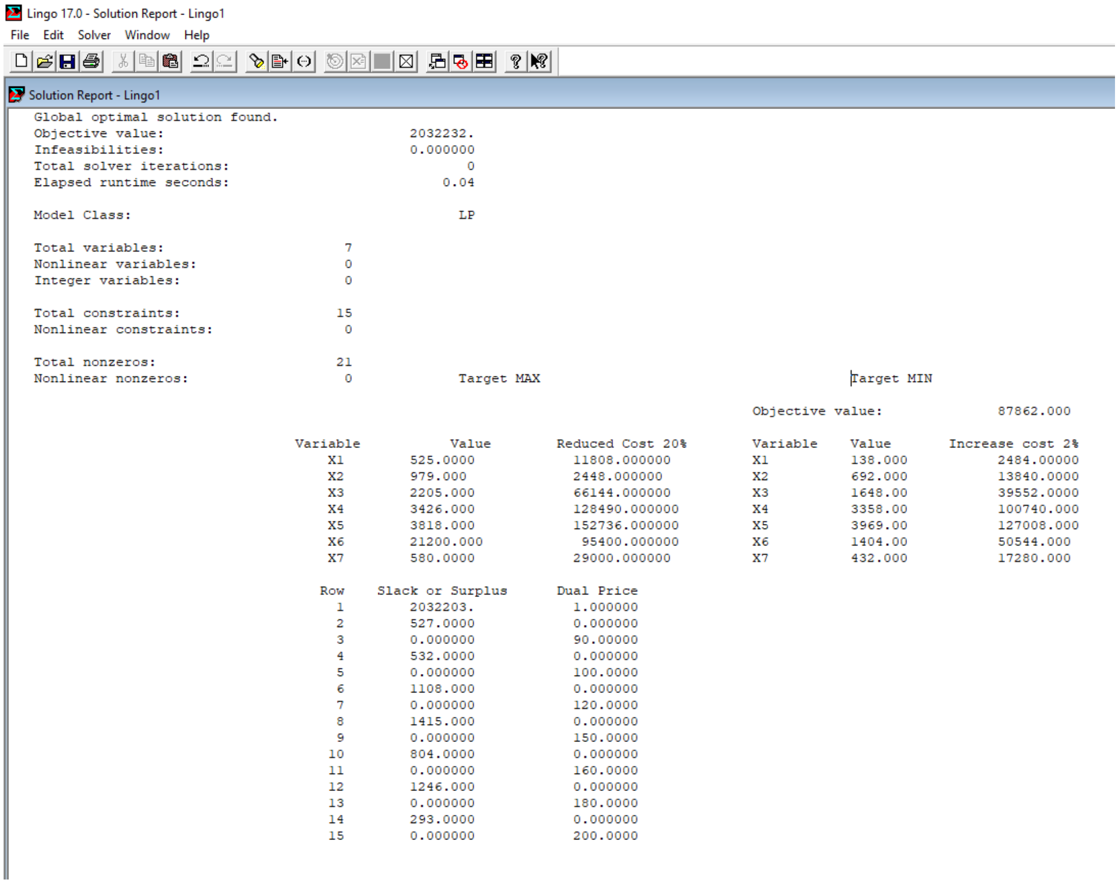


Figure 2. Lindo Cost Optimization Model

Based on the range of variables, the model suggests target values. In the observed example it's TR=2,032,232, which is 20% lower than the maximum revenue with CU=100%. The model decreases the value of variables and reduces costs starting from maximum values.

The model also satisfies the second inequation by adjusting the minimum values with the optimal ones from the first inequation and calculates the increase of costs (EC). The model indicates Slack or Surplus and Dual Price, which should be taken into consideration in the sensitivity analysis.

The results obtained are shown in the below figure.



Lingo 17.0 - Solution Report - Lingo1

File Edit Solver Window Help

Solution Report - Lingo1

Global optimal solution found.	
Objective value:	2032232.
Infeasibilities:	0.000000
Total solver iterations:	0
Elapsed runtime seconds:	0.04
Model Class:	LP
Total variables:	7
Nonlinear variables:	0
Integer variables:	0
Total constraints:	15
Nonlinear constraints:	0
Total nonzeros:	21
Nonlinear nonzeros:	0

Target MAX

Variable	Value	Reduced Cost 20%
X1	525.0000	11808.000000
X2	979.000	2448.000000
X3	2205.000	66144.000000
X4	3426.000	128490.000000
X5	3818.000	152736.000000
X6	21200.000	95400.000000
X7	580.0000	29000.000000

Target MIN

Objective value: 87862.000

Variable	Value	Increase cost 2%
X1	138.000	2484.00000
X2	692.000	13840.0000
X3	1648.00	39552.0000
X4	3358.00	100740.000
X5	3969.00	127008.000
X6	1404.00	50544.000
X7	432.000	17280.000

Row	Slack or Surplus	Dual Price
1	2032203.	1.000000
2	527.0000	0.000000
3	0.000000	90.00000
4	532.0000	0.000000
5	0.000000	100.0000
6	1108.000	0.000000
7	0.000000	120.0000
8	1415.000	0.000000
9	0.000000	150.0000
10	804.0000	0.000000
11	0.000000	160.0000
12	1246.000	0.000000
13	0.000000	180.0000
14	293.0000	0.000000
15	0.000000	200.0000

Figure 3 Results of the Lindo Model

The obtained optimization RESULT shows that the optimal solution would be for CU to amount to 80%, and accordingly, for EC to amount to 5% of total revenue. The result is expected and logical, but the program pointed to the "bottlenecks", i.e. the unevenness in the lengths of vessels and accordingly, to inadequate utilization of capacities.

However, as previously stated, the distribution of incoming vessels according to size is a problem to be dealt with by NTP managements through more proactive marketing and commercial policies.

5.2. Sensitivity Analysis

Finding the optimal solution does not conclude the problem solving analysis, but rather it should be completed by conducting the sensitivity analysis, aimed at examining changes in the model's output values as consequences of changes to individual input parameters of the model. The sensitivity analysis of solutions obtained by linear programming is carried out by using standard output data obtained by using the simplex algorithm.

Namely, the values of parameters in the optimization model are normally estimates. Given that models are created because of decisions to be made in the near or distant future, the estimate of parameter value (e.g. environmental costs) must be based on the prediction of their future values, which inevitably leads to mistakes.

Every increase in revenue proportionally increases investments into environmental protection, which is in line with socially responsible business. The optimal solution would be for every increase in traffic of vessels within an NTP to result in a proportional increase of pollution costs. Only this approach can satisfy the interests of environmental protection.

Apart from the above, one should always keep in mind the risk of pollution on a greater scale. The basic risk relation is R= l x c, where the ***l*** stands for the likelihood or frequency of an incident and the ***c*** stands for the consequence which can range from insignificant to catastrophic.

The definition of risk implies that the risk will be greater if the number of certain occurrences is higher, which indicates that maximizing the intake of boats (up to full capacity) entails the increased risk of an incident. Therefore, from the viewpoint of marine accidents, it is inopportune to strive for maximum capacity utilization.

Environmental protection is a process starting with the philosophy on the need to preserve the environment, which therefore does not end until there is a balance between the natural environment system and its exploitation. All the research can be presented through the algorithm of preserving the environment in an NTP in three possible scenarios.

5.3. Algorithm of Sustainable Development of an NTP

The algorithm of sustainable development of the NTP is a logical sequence of actions and decisions to be implemented to come from the initial intention to the desired objective. Before setting up the algorithm, one must define the answers to the basic questions posed in the below table.

Table 4.1 Requirements for ensuring the quality of the environment preservation process

WHAT IS THE DESIRED RESULT?	ENABLE SUSTAINABLE DEVELOPMENT OF AN NTP
Who makes the decisions?	NTP management
Who are the executors?	Quality management system, Environmental protection service
What should be done?	Carry out vertical and horizontal differentiation according to technical complexity, quality requirements and environmental protection within the NTP
What are the objectives?	I. Keeping the current market position by maintaining the current product quality with the current environment protection system; II. Improving the market position by creating a competitive advantage based on the quality of service and systemic improvement of activities related to the protection of nature and preservation of the environment; III. Achieving the leading position on the market based on the eco NTP brand
How to achieve them?	I. Through systemic monitoring of the environment within the NTP II. Through systemic investments into the environment protection system III. Through systemic education of all stakeholders in nautical tourism
What are the obstacles?	Environment protection costs
What are the decision – making parameters?	Survival in the market, investment/achievement ratio, opinions by expert consultants, benchmarking, signals from the surroundings.

Source: Authors

The answers provided will create the following scenarios:

Table 2 Sustainable development scenarios

SCENARIO I		SCENARIO II		SCENARIO III	
The existing quality management and environment protection systems		Systemic improvement of the quality of infrastructure and superstructure of the NTP, investments into modern energy management equipment, use and treatment of water		Reaching excellence in quality management and environment protection systems; meeting all requirements of preserving the environment	
CU = 68%	Environment protection costs TR*0,03	CU = 80%	Environment protection costs TR*0,05	CU = 99%	Environment protection costs TR*0,08
Permanent exposure to inspections, monitoring by environmental organizations, activists, scrutiny and evaluations of professional publications….		Obtaining passing marks from all relevant stakeholders in environmental protection, raising the NTP's rating, cooperation with the local community concerning the improvement of environmental protection		Creating the brand of an ECO NTP, reaching the leading position in the nautical tourism market; socially responsible business	

Source: Authors

The proposed scenarios show that any plans for sustainable development of an NTP is based on three key factors, specifically: capacity utilization – CU, total revenue from primary business activity – TR and environmental costs shown as a percentage of the TR.

6. CONCLUSION

If optimal results are desired, one should strive for systemic planning of the development of nautical tourism ports and training personnel for successful management and organization of existing ports and ports yet to be constructed. With the objective of minimizing pollution coming from nautical tourism and nautical tourism ports, any disposal of waste into the sea, however small, should be prevented, and the removal of all waste and oils from the sea surface and the coast should be ensured. The consequences of the potential slowing down of the replacement of sea water within the marina should be compensated with the prohibition of introduction of any waste, particularly organic (nitrates and phosphates) waste resulting from washing dishes, taking showers or food preparation on boats. Disposal of any solid waste into the sea should be strictly prohibited, as well as the discharge of sewage from boats.

One of the biggest problems in environment protection during the use of the development is preventing the pollution from every - day work and life on board the vessels (various types of waste, sewage). In that sense, the method of discharging the sewage tanks should be worked out and determined. To reduce the pollution, the sewage should be discharged and disposed according to relevant legislation in force in Croatia, while all opposite actions should be strictly prohibited and penalized.

It is clear that damage from pollution cannot be entirely avoided, but it must be minimized to the greatest extent possible. A quality control system should be set up in nautical tourism ports due to its accelerated development, which should contribute to raising awareness on possible long – term consequences alongside the legal measures. Apart from the above, the surveillance system for those individuals avoiding compensation of damages should be enhanced and those individuals should be penalized by fines and other measures.

REFERENCES

[1] A. V. Padovan, »Odgovornost luke nautičkog turizma iz ugovora o vezu i osiguranju,« Poredbeno pomorsko pravo, svez. 52, br. 167, pp. 1-35, 2013.

[2] NN, Uredba o uvjetima za dolazak i boravak stranih jahti i brodica namijenjenih sportu i razonodi u unutarnjim morskim vodama i teritorijalnom moru Republike Hrvatske, Zagreb: Narodne novine, 2017/50.

[3] D. Đerđa, »Ugovor o koncesiji,« Hrvatska javna uprava, svez. 6, br. 3, pp. 120-185, 2006.

[4] T. Luković et all., Nautički turizam Hrvatske, Split: Redak d.o.o., 2015.

[5] D. Gračan, »Can Scuttling Contribute to Expanding the Croatian Tourism Offering,« u 3rd International Scientific Conference Tourism in Southern and Eastern Europe 2015, Dubrovnik, 2015.

[6] M. Z. A. Kovačić, »A Comparative Analysis of Accommodation Capacities of Nautical Tourism Ports in Croatia and in the Primorje-Gorski Kotar County,« Pomorski zbornik, svez. 54, br. 1, pp. 75-83, 2018.

[7] K. Dogan i T. Mršić, »Očuvanje prirodnih resursa nautičkog turizma u Republici Hrvatskoj,« Pomorski zbornik, pp. 73-85, 2013.

[8] Z. Cerović, S. Janković i D. Vlašić, »Benchmarking marina,« Sveucilište u Rijeci, Fakultet za menadžment u turizmu i ugostiteljstvu, Opatija, 2018.

[9] M. Kovačić, »Spatial characteristics of planning and construction of nautical tourism 2ports,« Geoadria, svez. 12, br. 2, pp. 131-147, 2007.

[10] R. Zelenika i V. Vidučić, »Model razvitka nautičkog turizma u Republici Hrvatskoj do godine 2015.,« Ekonomski pregled, svez. 58, br. 9-7, pp. 522-544, 2007.

[11] A. Jugović, et. All. »Sustainable development model for nautical tourism ports,« Tourism and hospitality management, svez. 17, br. 2, pp. 175-186, 2011.

[12] T. Luković, Nautičko turističko tržište u teoriji i praksi Hrvatske i europskog dijela Mediterana. Split, Split: Hrvatski hidrografski institut, 2007.

[13] M. Pijaca, » Pravni odnosi između marine i charter kompanije u svezi sugovorom o vezu – prikaz hrvatske i komparativne poslovne prakse. PPP. Vol.57 (2018), 172, pp.253-284,« PPP, svez. 57, br. 1, pp. 253-284.

[14] Ministarstvo turizma RH, Strategija razvoja nautičkog turizma Republike Hrvatske za razdoblje 2009. – 2019., Zagreb: Ministarstvo turizma, 2008.

[15] Z. Klarić, »Razvoj ekoturizma i ruralnog turizma pridonosi slici Hrvatske, Okoš, br. 111/2002.,« Okoliš, p. 111, 2002.

[16] M. Peršić, »Računovodstvo okoliša i održivi razvoj turizma,« u Održivi razvoj turizma, Rijeka, Fakultet za turistički i hotelski menadžment Opatija, Sveučilišta u Rijeci, 2005, pp. 98-118.

[17] M. Kovačić, Komadina P., Upravljanje obalnim područjem i održivi razvoj, Rijeka: Pomorski fakultet Rijeka, 2011.

[18] N. Cukrov, gl. istr. »Studija o utjecaju na okoliš luke nautičkog turizma Mandalina – Kuline,« Institit Ruđer Bošković, Zagreb, 2008.

[19] L. Šantić, S. Vilke, S. i N. Grubišić, »Čimbenici štetnog djelovanja cruising-turizma na brodski okoliš,« Naše more, svez. 58, br. 5-6, pp. 229-243, 2011.

[20] NN, Pomorski zakonik, Zagreb: Narodne novine, 2015/26.

[21] NN, Zakon o pomorskom dobru i morskim lukama, Zagreb: Narodne novine d.o.o., 2016/56.

[22] NN, Pravilnik o razvrstavanju i kategorizaciji luka nautičkog turizma, Zagreb: Narodne novine d.o.o., 2008/72.

[23] EC, »Communication from the Commision to the European Parliament, the Council, European Economic and Social Committee and the Committee of the Regions concerning the European Union Strategy for the Adriatic and Ionian Region,,« EC.

HUMAN MACHINE INTERFACE: INTERACTION OF OOWs WITH THE ECDIS SYSTEM

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Summary

Electronic Chart Display and Information System (ECDIS) is a computer maritime navigational system providing support to Officers Of the Watch (OOW's) in the execution of main navigational tasks. According to the International Maritime Organization (IMO), the primary scope of ECDIS is a contribution to navigation safety. The system represents an inevitable path towards paperless vessels and digital navigation. It implies, among other, ease of operation, smooth handling and integrity. However, OOW's are facing difficulties when they are interacting with the system. There are more than thirty official and approved ECDIS system manufacturers with their interface designs and software solutions. The mentioned differences can lead to potential unwanted situations. The aim of the paper is to identify the impact of different systems among navigational ranks, as well as consequences of non-standardized features beyond those regulated in Performance Standards. A dedicated, internationally distributed questionnaire was used to support this study, together with analysis of ECDIS-related marine accidents' and official detention lists. The research results showed different levels of potential issues. As seen from the OOWs perspective, insufficient standardization of system settings, display presentation, functions and terminology between models represents main observations of the conducted analysis. Maritime accidents' causes, and detentions of vessels supports these findings, together with observed insufficient knowledge required for proper handling with the system. These potential threats can negatively impact the safety of navigation. The paper discusses the proposal and recommendation of a more simplified, intuitive and user-friendly system which could comply between all manufacturers. A more proper education in conjunction with more simplified Human Machine Interface (HMI) between OOW's and ECDIS is suggested and the achievement means are discussed. The proposed solutions are oriented towards maritime navigation safety improvement.

Keywords: Officers Of the Watch, Human Machine Interface, Electronic Chart Display and Information System, ecdis eho

1. INTRODUCTION

Maritime navigation is a complex process of planning, monitoring and executing of the sea passage venture. To complete sea passage successfully, the navigator has many navigational aids on his disposal. One of the most crucial navigational aids are Paper Navigational Charts (PNC). PNC have undergone through the major change during the last three decades. For a long time, PNC were the only IMO approved charts. With the modernization of the navigational aids, change has arrived on the cartography field in the form of Electronic Navigation Chart (ENC). ENC is intended to be used with an ECDIS, computer based maritime navigation system. International Convention for the Safety of Life at Sea (SOLAS) 1974, in Chapter V- *Safety of navigation*, regulates nautical charts and nautical publications carriage requirements. Approved ECDIS is a navigational aid, which provides significant help to navigator if it is utilized as a primary navigational means. It was left to the ship owners to implement the system on a voluntary basis but before the deadline date, depending on the ship's size, type and fact if it is new built or existing ship in service. On the July 1st, 2018 ECDIS implementation transitional period ended, and the system became a primary navigational mean for most SOLAS vessels engaged into international voyages [20].

Regulations dictate a back-up arrangement of the system, which can be one of the following means*:* *i)* An appropriate folio of PNC, *ii)* Separate independent system with available emergency electrical power supply if needed and *iii)* Chart Radar (CR), additional computer based maritime navigation system where ENCs are loaded into Radio Detection And Ranging (RADAR) system [19, 22, 23]. If navigator doesn't understand the system or utilize it incorrectly, it may lead to misinterpretation and serious accidents. As it will be presented, according to official marine accidents investigation reports [35], incorrect use or misunderstanding of the system was a contributing or root cause for several accidents. A significant share of reported vessel detentions [1, 37] refers to breaches pertaining to ECDIS. To satisfy IMO regulations and Standards of Training, Certification and Watchkeeping (STCW) standards, before taking over maritime navigation duties, every OOW must possess flag state approved *generic ECDIS certificate* [39]. Approved certification may follow IMO Model Course 1.27 and should ensure that training attendee learns to use ECDIS in all aspects of maritime navigation. The course is covering 40 topics divided into 5 subject areas [31]. International Safety Management (ISM) Code requires from shipping companies to ensure that personnel involved in the company's safety management system understands rules and regulations and that adequate training is provided [21]. The company is obliged to ensure that all OOWs operating with the system are properly trained and familiar with all features before utilizing it operationally at sea as a navigational aid, i.e. *equipment specific ECDIS training*. The ECDIS interface serves as a point of interaction between OOW and the system, representing an example of HMI defined by [26, 27, 28].

From the operational aspect of the system, several utilization issues were noted, such as the difference between PNC and ENC symbology, an occurrence that certain symbols are not visible on the same ENC cell but on a different scale, some ENC producers have not magnetic variation information displayed, inconsistencies between ENCs and PNC, possibility of areas with ENCs coverage gaps, etc. [11, 25, 30, 32].

This paper discusses the interaction of OOWs with ECDIS system. The purpose of the proposed research was to identify possible problems which OOWs' are facing during their maritime navigational tasks when interacting with ECDIS interface. Official maritime accidents' reports were investigated to identify causes where the system contributed to the final outcome – the accident. Law makers and maritime inspectors' detentions which in turn resulted with system related deficiencies findings were analyzed as well. The analyses' results and findings were the motivation for the further research, which was directed towards opinions from OOWs as central system end-users. A dedicated questionnaire was created in terms of OOW-ECDIS HMI, and it was distributed to navigational ranks on international basis. The undertaken research study recognized several points of interest in relation to OOW and ECDIS system HMI. Before reaching the market as a final product, the system needs to fulfill different settings, display, functions and terminology standards and requirement. Every manufacturer has his solutions on how to achieve these requirements, and in result, there is a final product which slightly differs between different manufacturers with hardware, software and interface design. Even though ECDIS undeniably contributes to the safety of navigation, there are several issues which are requiring special focus. It is necessary to take into consideration knowledge of the OOW, duration of the OOW hands on experience, fact if OOW works only with one ECDIS manufacturer and model or if OOW changes different vessels with different systems more frequently.

The paper is organized as follows. After the short introduction on the research problem, general features are summarized together with previous related research. In the following chapter, utilized methods for data collection and analysis are described. Results are presented subsequently, consisting of ECDIS related accidents, inspection detentions and observations derived from questionnaire analysis. In the concluding chapter, research results are summarized together with solutions' proposals and desirable guidelines for the continuation of the research.

2. GENERAL ECDIS FEATURES AND PREVIOUS RESEARCH

Introduction of ECDIS represents one of the most significant steps in maritime navigation. The system reduces OOWs workload and it contributes to safety of navigation with task automation and speeded up voyage planning. The architecture of ECDIS is presented on Figure 1. The system consists of hardware and software, user display and updated databases converted into system-compatible Electronic Navigational Charts (SENCs). The system integrates data and information from mandatory and additional sensors. Every system model must fulfill International Hydrographic Organization (IHO), IMO and International Electrotehnical Commission (IEC) regulations and performance standards to be approved and installed on-board vessels [9, 10, 12, 13, 14, 15, 16, 17, 18, 19, 24].

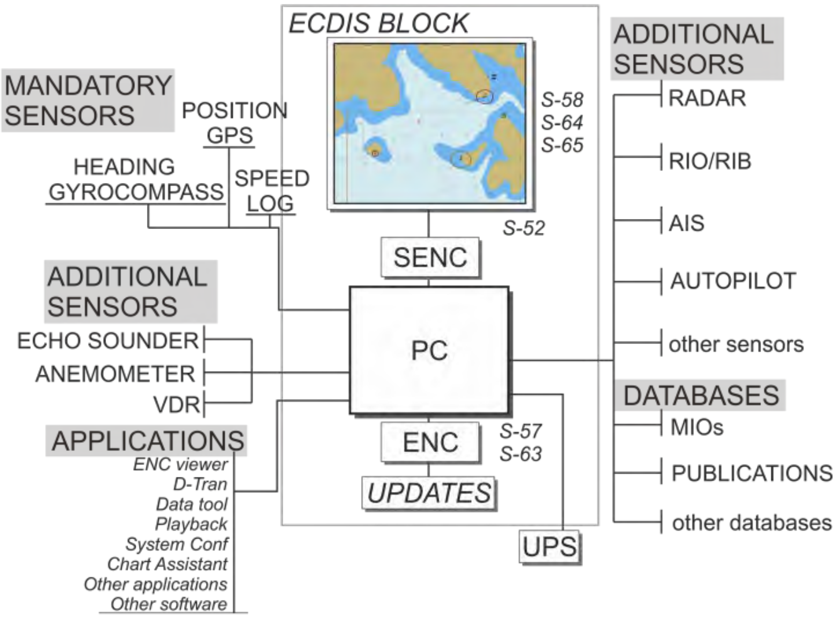

Figure 1 ECDIS architecture. Based on the ©Transas NaviSailor 4000 example

Source: [3, 4]

ECDIS enables simplified planning and monitoring of the sea passage maritime venture when compared to traditional navigation; however, issues in ECDIS use and necessary system improvements were identified [11]. Knowing that there are more than 30 officially approved ECDIS manufacturers [6] with their interface design and graphical solutions it is not hard to recognize difficult task standing in front of the OOW, who needs to interact with the system interface. It is necessary that OOWs are aware of the system limitations. The automation of the system can potentially create space for errors [26]. System design should help to OOW in error risk mitigation and contribute to the HMI goal [28], and potentially risky situations identified immediately with HMI central alert system [29].

ECDIS interaction training process and qualifications are equally important as PNC working skills [33]. Besides navigation safety, the system is nowadays used with additional applications as a concept development in the function of environment protection [40, 41]. Despite the indisputable fact that ECDIS system contributes to the safety of navigation, "ECDIS assisted accidents" [36] term started to appear in the official maritime accidents' reports. Several studies highlighted the importance of proper ECDIS education and training for the safety of navigation [2, 3, 5, 42]. In pursuance of ECDIS benefits and system limitation recognition, a change in navigation understanding is required [38]. In the process of planning and executing of the maritime venture ECDIS system is playing one of the most important roles [34]. Even though the interpretation of the ECDIS system differs between ranks of OOW's and their engagements with the system [4], user's knowledge has a most important role in the contribution to the safety of navigation [34].

The mentioned observations and statements were the motivation for the proposed research, focused on OOWs' interpretation and handling with the system. This issue is elaborated through ECDIS-related accidents, PSC detentions related to the system, and standpoints of OOWs regarding their interaction with ECDIS. In the following chapter, the methodology of the conducted research is presented.

3. METHODOLOGY

The research methodology consists of several inter-related phases. Official maritime accident reports [7, 8, 35] were investigated as reported from the January 1st, 2008 onwards. The accidents where ECDIS was a root or contributing cause were further analyzed [35]. Subsequently, authors focused on the Port State Control (PSC) inspections and reported detentions of SOLAS vessels as occurred in 2018 [1, 37]. Detentions related to the system were filtered and analyzed, with emphasis on causes of detentions. Quality and results of the collected data, which are representing actual events (accidents) and precautionary measures (detentions) served as a basis for the construction of the questionnaire, which in turn represents the standpoints of OOWs as central interactors with the system. The questionnaire was distributed to seafarers on an international basis. It contains 19 introductory and topic-related questions with an emphasis on the interaction of OOWs with ECDIS. The survey was directed to legitimate respondents; navigational ranks with the possession of, at least, the *Generic ECDIS certificate*. The survey was conducted after the ECDIS transitional period completion.

Two introductory questions were used for respondent's profile categorization: navigational rank of respondents and their sea service experience (in years). For the purpose of the study, six questions related to the HMI topic were analyzed:

- How many approved ECDIS systems (manufacturer and/or model) have you operated during your career? (Q1)
- When your substitute embarks on the vessel how much time do you take to discuss ECDIS system on board? (Q2)
- In reference to previous question do you find that time as sufficient or insufficient? (Q3)
- Did you ever take over duty without sufficient time to familiarize yourself with the ECDIS system on board? (Q4)
- Do you find it challenging and time consuming to become familiar with ECDIS system every time when you change ship with different ECDIS system (manufacturer and/or model)? (Q5)
- Do you think that default ECDIS settings should be standardized between all approved ECDIS manufacturers and models? (Q6)

The answers were divided into two main categories: profile of the survey participants (introductory questions) and their responds (topic related questions). Respondents were categorized according to navigational ranks and sea experience in years. Summarized results are given for six elaborated questions: Q1-Q6. The results, analysis and discussion of results are presented in the following chapters.

4. RESULTS

4.1. ECDIS-related accidents

For the sake of safe maritime navigation with ECDIS system, three requirements must be fulfilled: equipment must be in good technical condition, the system has to be set up properly and OOWs have to be trained adequately. After reviewing accidents' reports where ECDIS played the major role it was noted that the system has not been utilized in accordance with guidance and instructions provided by manufacturers and lawmakers. Maritime accidents where incorrect utilization of the system had root cause, or it has contributed to the accident are summarized in Table 1.

Table 1 Maritime accidents with the ECDIS system as a major or contributing cause [35]

	Vessel name	Date	Accident type	Navigational equipment	Crew certification concerning ECDIS
1	Muros	December 3rd, 2016	Grounding	ECDIS	All generic and equipment specific training
2	CMA CGM Vasco de Gama	August 22nd, 2016	Grounding	ECDIS PNC backup	All generic and equipment specific training
3	Commodore Clipper	July 14th, 2014	Grounding	ECDIS	All generic and equipment specific training
4	Rickmers Dubai	January 11th, 2014	Collision	ECDIS	All generic
5	Ovit	September 18th, 2013	Grounding	ECDIS	All generic and equipment specific training
6	Dart	August 1st, 2013	Grounding	ECDIS	Not mentioned in the report
7	Beaumont	December 12th, 2012	Grounding	Electronic Chart System, Paper Chart Folio	Not mentioned in the report
8	CSL Thames	August 9th, 2011	Grounding	ECDIS	All generic
9	CFL Performer	May 12th, 2008	Grounding	ECDIS, Paper Chart Folio	Master equipment specific OOWs none
10	Pride of Canterbury	January 31st, 2008	Grounding	ECDIS, Paper Chart Folio	Master equipment specific OOWs none

Source: Authors

The causes can subsequently be summarized into following sub-groups: improperly trained officers (3, 8, 9, 10), poor passage planning (1, 2, 3, 5), disabled system alarms by OOWs (1, 2, 3, 7), inoperative system alarms (5, 6, 8), over-reliance on system (4, 5, 8), safety contour parameters not set properly (3, 8), misinterpretation of displayed symbols (10) and inoperative primary positioning system (6). Certain accidents consisted of more than one defined sub-group, e.g. in the case of the accident No. 3, which occurred as the combination of improper training, inadequate preparation of the passage planning, denial of system alarms and incorrect settlement of safety parameters. In Accident No. 1, similar chain of errors was found, leading to grounding of the vessel. Except for one case (in Accident No.7), the official ECDIS was a part of navigational equipment, mostly the only means of navigation.

All of the reasons can be summoned as *ECDIS not used in accordance with standards* term, which potentially implies to improper level of handling knowledge. This was the motivation to investigate further and to consult ECDIS-related inspection detentions' databases. The results are presented in the following section.

4.2. ECDIS-related inspection detentions

In 2018, Australian Maritime Safety Agency (AMSA) reported detentions of 157 vessels. Deficiencies related to ECDIS are noted under area 3 (ISM Code) and area 4 (Wheelhouse) [1]. Detentions pertaining to the ECDIS system are divided into two groups (Figure 2). A total of 8 detentions (5 %) refer to the ECDIS system together with other deficiencies. Among them, 2 detentions (1 %) refer to deficiencies pertaining solely to the system.

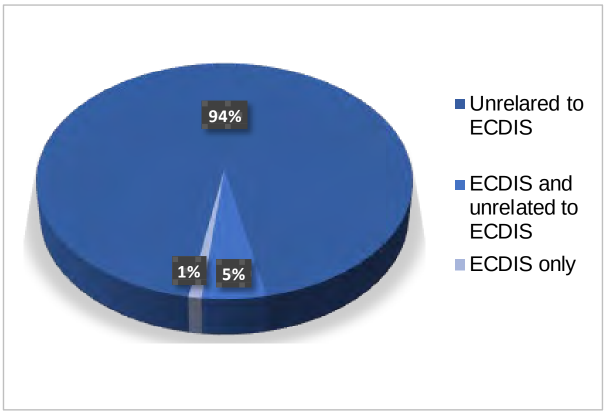

Figure 2 ECDIS related detentions share, according to [1]

Source: Authors

During 2018, PSC inspectors under Tokyo Memorandum membership have detained a total of 934 vessels, 17 of which were related to the system with other deficiencies, and one was related directly due to the system. The share of 1.65 % of all deficiencies under Tokyo Memorandum PSC jurisdiction is noted under regulation number 10112: Safety of Navigation, Electronic charts [37]. Tokyo Memorandum PSC detention share is presented on Figure 3.

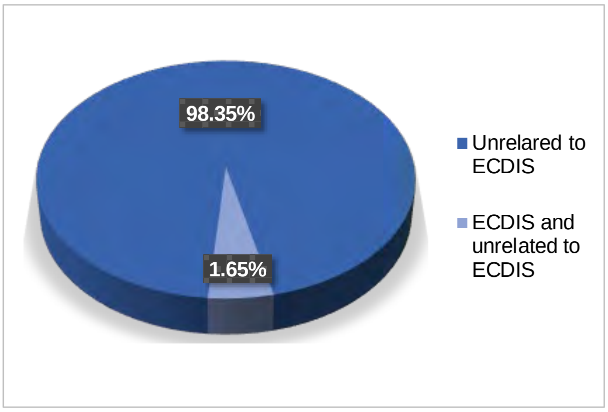

Figure 3 Tokyo Memorandum 2018 detentions share, according to [37]

Source: Authors

Unwanted events and their forming, that occurred as ECDIS-related were analyzed so far, together with legal countermeasures and related PSC inspections. In the following section, analyses and summarized results of the conducted HMI survey are presented, which, as opposed to previous analyses, reviews a feedback of the end-users of the system.

4.3. Results of the HMI survey

The total amount of 133 seafarers participated in the survey. Respondents' rank and sea time experience are shown on Figure 4. The share of respondents is as follows: 44 Masters, 10 Staff Captains, 35 Chief Officers, 10 First Officers Navigation, 23 Second Officers, 8 Third Officers and 3 Undefined respondents. Sea time experience of the survey participants is divided into 5 categories: respondents with less than 5 years of the sea time experience (12 %), respondents from 5 till 10 years of the sea time experience (27 %), respondents from 10 till 15 years of the sea time experience (27 %), respondents from 15 till 20 years of the sea time experience (15 %) and respondents with more than 20 years of the sea time experience (19 %).

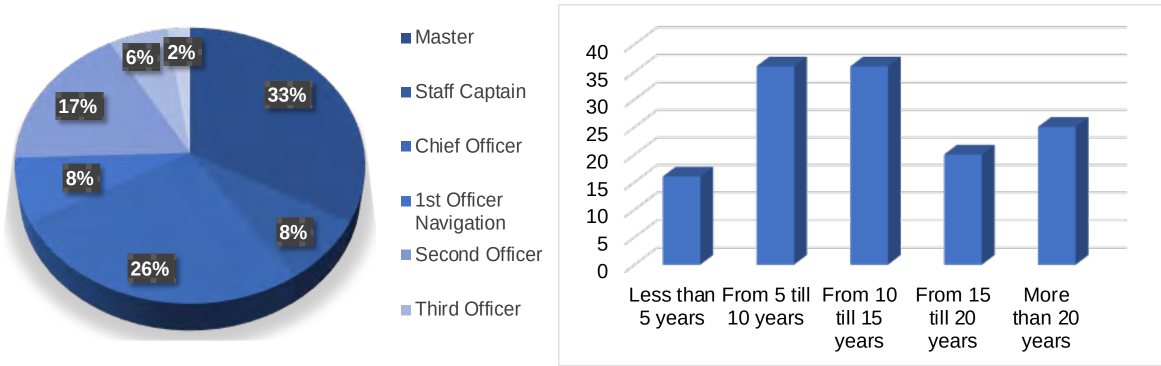

Figure 4 Navigational ranks of survey participants (left) and participants' sea experience (in years) (right)

Source: Authors

Share of answers regarding Q1 is presented on Figure 5. There are 21 participants who have operated with 1 ECDIS system during their carrer, 43 participants answered that they have operated with 2 ECDIS systems during their career, 31 participant answered that they have operated with 3 ECDIS systems during their career, and 38 participants answered that they have operated with more than 3 ECDIS systems during their career.

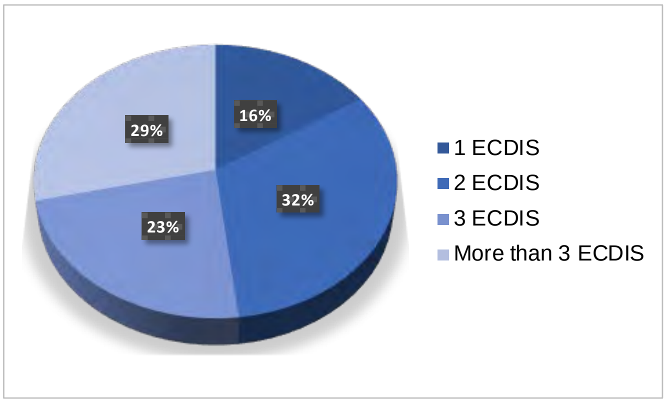

Figure 5 Share of answers regarding Q1 – *How many approved ECDIS systems (manufacturer and/or model) have you operated during your career?*

Source: Authors

Before relieved officer disembarks from the vessel she/he spends some time in hand over the discussion with hers/his substitute. Part of the hand over discussion includes discussion about ECDIS system on board. There are 98 participants who had answered that they spend less than 1 hour with their relievers in discussion about ECDIS system, 23 participants answered that they spend from 1 to 3 hours in discussion about ECDIS system, 10 participants answered that they spend from 3 to 6 hours in discussion about ECDIS system and 2 participants answered that they spend more than 6 hours in discussion about ECDIS system. The time frame that OOW spends in the discussion about ECDIS system on board is presented on Figure 6.

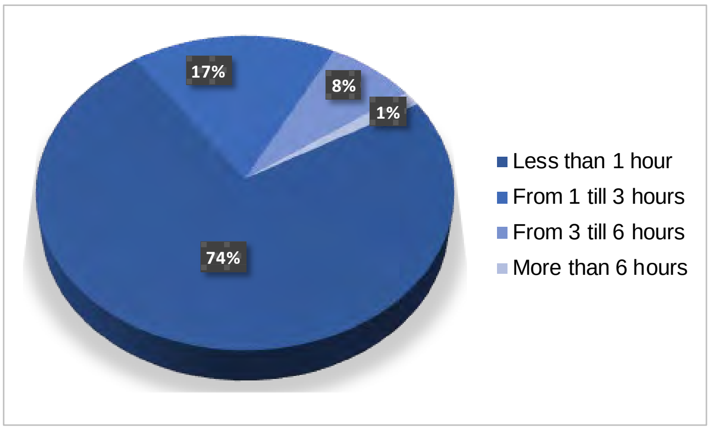

Figure 6 Share of answers regarding Q2 - *When your substitute embarks on the vessel how much time do you take to discuss ECDIS system on board?*

Source: Authors

In reference to hand over discussion about ECDIS system on board, 33 participants answered that they consider their discussion time about ECDIS system insufficient while 100 participants consider hand over discussion time concerning ECDIS system as sufficient. Figure 7 presents OOW's opinion regarding the ECDIS system hand over discussion sufficiency.

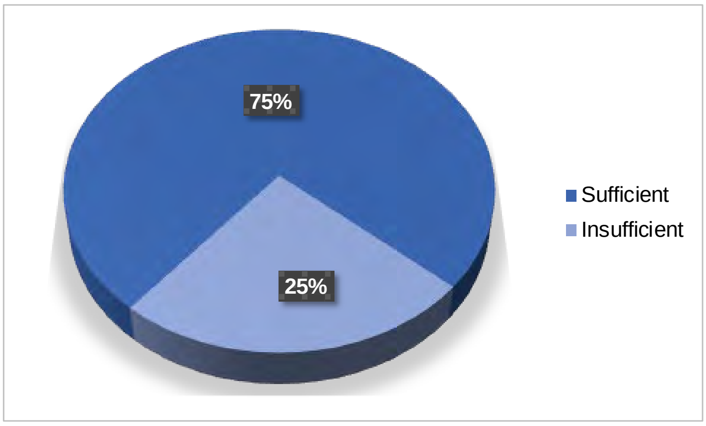

Figure 7 Share of answers regarding Q3 - *Do you find hand over discussion time about ECDIS system as sufficient or insufficient?*

Source: Authors

In Figure 8 is presented share of answers regarding Q4. There are 73 participants (55 %) who responded that they had taken over navigational duty without enough familiarization with ECDIS system and 60 participants (45 %) responded that they had never taken over navigational duties without sufficient familiarization with ECDIS system.

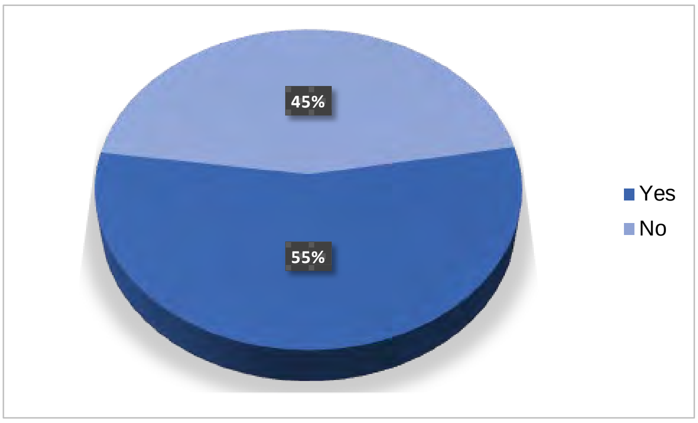

Figure 8 Share of answers regarding Q4 - *Did you ever take over duty without sufficient time to familiarize yourself with ECDIS system on board?*

Source: Authors

In Figure 9, the share of answers regarding problems in familiarization with the system is presented. Most of the survey participants (98) find the ECDIS familiarization process as challenging and time consuming while 34 participants do not experience the familiarization process as an issue.

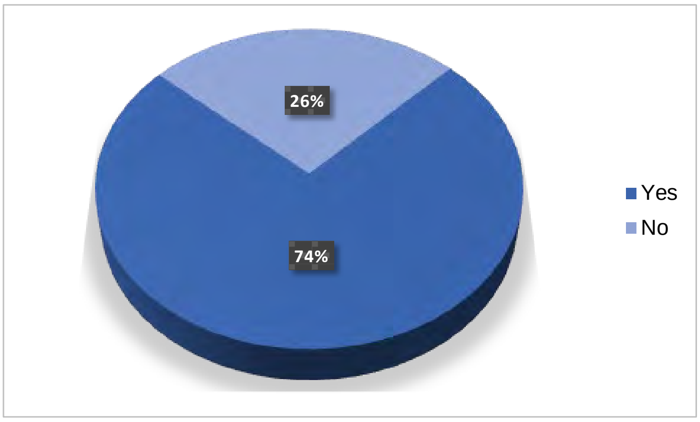

Figure 9 Share of answers regarding Q5 - *Do you find it challenging and time consuming to become familiar with ECDIS system every time when you change ship with different ECDIS system (manufacturer and/or model)?*

Source: Authors

Share of answers regarding opinion on standardization is presented on Figure 10. Majority of survey participants (125, or 94 %) agrees that default ECDIS settings should be standardized between different ECDIS manufacturers and models, while 8 participants (6 %) do not agree with this statement.

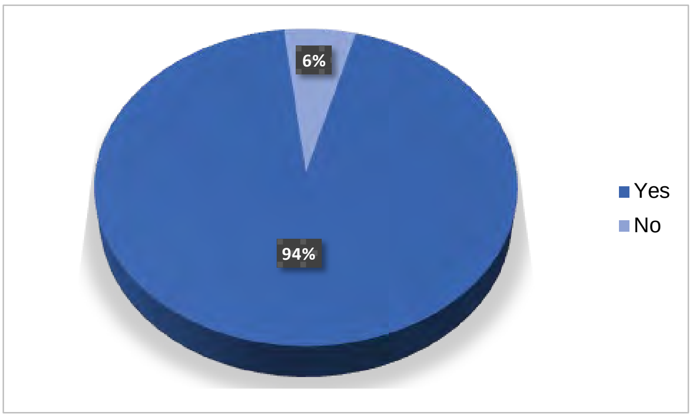

Figure 10 Share of answers regarding Q6 - Do *you think that default ECDIS settings should be standardized between all approved ECDIS manufacturers and models?*

Source: Authors

Majority of ECDIS-related maritime accidents are pertaining solely to errors related to the human interaction with the system, even though accidents pertaining to the aspect of technical system malfunctions cannot be completely ruled out. When it comes to PSC inspections and detentions, a human lack of knowledge, and difficulties they are facing during system handling is identified.

Most OOWs (84 %) interacted with more than one system. Before commencement with system handling, during the hand over discussion, 74 % OOWs invest less than 1 hour of their time to discuss the system. The majority (75 %) considers their discussion time to be enough even though 55 % took over duty without being sufficiently familiarized. Finally, about the same number (74 %) of respondents finds challenging and time consuming to familiarize with a different system, and almost all of respondents (94 %) agrees about the necessity of standardization between system manufacturers/models. The research results are discussed in the following chapter.

5. DISCUSSION

The research results are categorized into three segments: ECDIS marine accident reports, ECDIS-related PSC detentions and survey results of a questionnaire elaborating the interaction of OOWs with the system. After analyzing research results, authors pointed out two components which are common for all segments: *i)* human and *ii)* machine. In a perfect scenario, there would not be a possibility for mistakes; human lives at sea would not be in danger and ships would not be exposed to perils of the sea. However, humans are making mistakes when they are interacting with machines and especially with newly introduced technologies [27]. Maritime accidents' analysis showed that those mistakes could have a huge impact on safety at sea. They can cause damage to the ships, environment and ultimately loss of life at sea. PSC inspectors are inspecting vessels engaged in international voyages around the world. During their inspection vessels can be detained for numerous reasons other than those pertaining to the system. Approximately 6% of all AMSA detentions falls under findings related to ECDIS. Officials under Tokyo Memorandum jurisdiction have detained 17 out of 943 vessels due to the breaches related to the system. PSC detention reports pointed out the importance of the inspectors' preventive work by checking the knowledge of the OOW's and ECDIS systems on board the ships. If any malfunctioned equipment is detected and/or if OOW doesn't demonstrate good knowledge and skill in system operation, the vessel will be prevented from sailing until those findings are not rectified. Following are some of the examples why PSC officials detained vessels: ECDIS safety procedures not being met, ECDIS critical safety parameters incorrectly set, OOW's not familiar with the function and critical settings, or ENC's missing or not updated [1, 37].

The survey results showed that most respondents (84 %) have operated with more than one ECDIS system during their career. Meanwhile, the majority (74 %) of respondents have on their disposal less of one hour for the handover with the system. A measurable number of survey participants (25 %) finds their hand over discussion about ECDIS system to be insufficient. According to survey analysis, OOWs do not spare much time to pass relevant information to their relievers. On the other hand, most of OOWs finds challenging and time consuming to become familiar with the system whenever they change the vessel with a different system. Ultimately, more than half questionnaire respondents, at some point during their career, took over duty without enough time to familiarize themselves with the system. Accidents' reports pointed out in which direction that kind of flighty approach to such a complex and important maritime navigational system had led. To determine the reason why more than half questionnaire respondents took over duty without enough time to familiarize themselves with the system on board, it will be necessary to deepen research further and point out the root cause of the problem. It will be necessary to find out is it because of the ECDIS complexity, technical reasons, OOWs' knowledge, insufficient standardization among the manufacturers or something else.

When OOWs are taking over duty, they are becoming fully responsible for the safe and smooth navigation of the vessel. Keeping in mind all maritime accidents in which ECDIS system played a notable role, special focus should be concentrated on 55 % of survey participants who were at some point of their career responsible for safe navigation of the ship without being sufficiently familiarized about all ECDIS features. Majority of the survey participants agreed that different interface design between ECDIS manufacturers has an impact on OOWs familiarization time and interaction with ECDIS system, making it challenging and time consuming. Finally, most of the questionnaire respondents had agreed that ECDIS settings, display, functions and terminology should be sufficiently standardized between manufacturers. The study findings indicate a potential relation between lack of standardization and unwanted events, ranging from negative inspection outcomes to maritime accidents.

6. CONCLUSION AND FURTHER TENDENCIES

In the proposed paper, interaction between OOWs and ECDIS system has been discussed in terms of the Human-Machine Interface. Dedicated survey-based study pointed out several interesting answers and findings, where majority of respondents agreed about the problem existence. The aim of the research was a contribution to the improvement of the safety of navigation and identification of possible need for better education and simplified HMI. As a main problem, the insufficient standardization of the ECDIS settings, display, functions and terminology between system manufacturers is identified and subsequently confirmed. This problem has an impact on the necessary time that OOW needs to become familiar and confident when interacting with the system. Sufficient standardization should contribute to research goals. In order to obtain a deeper insight on opinions, further research activities should be considered. The participants (end-users) should be categorized according to their opinions regarding system complexity, hand over discussion time and formally being in charge.

Additionally, to further discuss the topic, it is necessary to consider several different facts. Individual knowledge of every OOW is different. Not all OOWs have undergone through the *equipment specific ECDIS training* in addition to *Generic ECDIS certification* properly. It is necessary to recognize the rank of the officer and the fact if he works with only one or more different ECDIS models and/or manufacturers. Finally, sea service time and OOW's valuable hands-on experience recognition serves of utmost importance. Statements and inferences which were derived from the research present a stable foundation for further research in the era of automated and integrated navigational systems' development, with the Officers Of the Watch as central interacting stakeholders, still.

ACKNOWLEDGMENT

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REFERENCES

[1] Australian Maritime Safety Authority (AMSA) (2018). Available from: https://www.amsa.gov.au/vessels-operators/port-state-control (Accessed February 26th, 2019)

[2] Brčić, D., Kos, S., Žuškin, S.: Navigation with ECDIS: Choosing the proper secondary positioning source. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 2015, Vol. 9, No. 3, pp. 317-326, (ISSN: 2083-6481), DOI: 10.12716/1001.09.03.03.

[3] Brčić, D., Kos, S., Žuškin, S.: Partial structural analysis of the ECDIS EHO research: The handling part, In: Rijavec, R. (ed.) Proceedings of the 24th International Symposium on Electronics in Transport (ISEP24). Ljubljana: Electrotechnical Association of Slovenia & ITS Slovenia, 2016, pp. 80-87, (ISBN: 978-961-6187-56-5).

[4] Brčić, D., Žuškin, S.: Towards Paperless Vessels: A Master's Perspective. Pomorski zbornik, 2018, Vol. 55 No. 1, pp. 183-199, (ISSN: 0554-6397), DOI: 10.18048/2018.00.12.

[5] Brčić, D., Žuškin, S., Barić M.: Observations on ECDIS Education and Training. In: Weintrit, A. (ed.) Proceedings of 12th International Conference on Marine Navigation and Safety of Sea Transportation (TransNav 17), Gdynia, Poland, 2017. London: CRC Press, 2017. pp. 29-36, (ISBN: 978-1-138-29762-3).

[6] ECDIS Regulations (2018). Available from: https://www.ecdisregs.com/approved-ecdis-systems/ (Accessed December 14th, 2018)

[7] Federal Bureau of Maritime Casualty Investigation (BSU) (2018). Available from: https://www.bsu-bund.de/EN/Publications/Unfallberichte/Unfallberichte_node.html (Accessed October 25th, 2018)

[8] French Marine Accident Investigation Office (BEAmer) (2018). Available from: http://www.bea-mer.developpement-durable.gouv.fr/about-us-r50.html (Accessed October 25th, 2018)

[9] International Electrotehnical Commission (IEC) (2015). Maritime navigation and radio communication equipment and systems – Electronic chart display and information system (ECDIS) – Operational and performance requirements, methods of testing and required test results. IEC 61174, Edition 4.0.

[10] International Electrotehnical Commission (IEC) (2014). Maritime navigation and radio communication equipment and systems – Presentation of navigation-related information on shipborne navigational displays – General requirements, methods of testing and required test results. IEC 62288, Edition 2.0.

[11] International Hydrographic Organization (IHO) (2014). IHO Report on the results of the ECDIS survey conducted by BIMCO and Denmark. Monaco: IHO.

[12] International Hydrographic Organization (IHO) (2014). S-52: Presentation Library, Annex A, Edition 4.0. Monaco: IHO.

[13] International Hydrographic Organization (IHO) (2014). S-52: Specifications for Chart Content and Display Aspects of ECDIS, Edition 6.1. Monaco: IHO.

[14] International Hydrographic Organization (IHO) (2000). S-57: IHO Transfer Standard for Digital Hydrographic Data. Edition 3.1. Monaco: IHO.

[15] International Hydrographic Organization (IHO) (2018). S-58: ENC Validation Check. Edition 6.1.0. Monaco: IHO.

[16] International Hydrographic Organization (IHO) (2015). S-63: Data Protection Scheme, Edition 1.2. Monaco: IHO.

[17] International Hydrographic Organization (IHO) (2017). S-64: Test Data Sets for ECDIS, Edition 3.0. Monaco: IHO.

[18] International Hydrographic Organization (IHO) (2017). S-65: Electronic Navigational Charts (ENCs) "Production, Maintenance and Distribution Guidance". Edition 2.1.0. Monaco: IHO.

[19] International Hydrographic Organization (IHO) (2018). Current IHO ECDIS and ENC Standards. Available from: https://www.iho.int/iho_pubs/IHO_Download.htm#Standards (Accessed April 8th, 2019)

[20] International Maritime Organization (IMO) (2014). International Convention for the Safety of Life at Sea, 1974 as amended. London: IMO.

[21] International Maritime Organization (IMO) (1993). International Safety Management Code (ISM). Resolution A.741(18): International Management Code For The Safe Operation Of Ships And For Pollution Prevention. London: IMO.

[22] International Maritime Organization (IMO) (1995). A.817 (19): Performance standards for Electronic Chart Display and Information Systems (ECDIS). London: IMO.

[23] International Maritime Organization (IMO) (1996). MSC.64 (67): Adoption of new and amended performance standards. London: IMO.

[24] International Maritime Organization (IMO) (2006). MSC.232 (82): Adoption of the revised performance standards for Electronic Chart Display and Information Systems (ECDIS). London: IMO.

[25] International Maritime Organization (IMO) (2009). NCSR 2/22/2: Report on monitoring of ECDIS issues by IHO. London: IMO, 2009.

[26] International Maritime Organization (IMO) (2000). MSC/Circ.982: Guidelines on ergonomic criteria for bridge equipment and layout. London: IMO.

[27] International Maritime Organization (IMO) (2003). MSC/Circ.1091: Issues to be considered when introducing new technology on board ship. London: IMO.

[28] International Maritime Organization (IMO) (2007). MSC.83 (28) Add.3: Adoption of the revised performance standards for Integrated Navigation Systems (INS). London: IMO.

[29] International Maritime Organization (IMO) (2010). MSC.87 (26) Add.1: Adoption of performance standards for bridge alert management. London: IMO.

[30] International Maritime Organization (IMO) (2010). MSC.1/Circ. 1391: Operating anomalies identified within ECDIS. London: IMO.

[31] International Maritime Organization (IMO) (2012). Model Course 1.27: Operational use of Electronic Chart Display and Information System. London: IMO.

[32] International Maritime Organization (IMO) (2013). NAV 59/12/1: Report on monitoring of ECDIS issues by IHO. London: IMO.

[33] Legieć, W.: ECDIS Users Genuine Qualification in Maritime Industry Great Demand. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 2016, Vol 10, No. 4, (ISSN: 2083-6481), DOI: 10.12716/1001.10.04.05 (Accessed June 12th, 2019)

[34] Lušić, Z., Bakota, M. and Mikelić, Z.: Human errors in ECDIS related accidents. 7th International Maritime Science Conference (IMSC), Solin, Croatia, 2017. pp. 230-242, (ISSN 1847-1498).

[35] Marine Accident Investigation Branch (MAIB) (2018). Available from: https://www.gov.uk/government/organisations/marine-accident-investigation-branch (Accessed October 25th, 2018)

[36] Nielsen, M., R.: How a ship´s bridge knows its position – ECDIS assisted accidents from a contemporary human factors perspective. Lund University, Lund, Sweden, 2016. Available from: http://lup.lub.lu.se/student-papers/record/8895474 (Accessed December 07th, 2018)

[37] Tokyo Memorandum Of Understanding (Tokyo MOU) (2018). Available from: http://www.tokyo-mou.org/inspections_detentions/ (Accessed February 28th, 2019)

[38] Weintrit, A.: Clarification, Systematization and General Classification of Electronic Chart Systems and Electronic Navigational Charts Used in Marine Navigation. Part 1 - Electronic Chart Systems. The International Journal on Marine Navigation and Safety of Sea Transportation (TRANSNAV), 2018, Vol 12, No. 4, (ISSN: 2083-6481), DOI: 10.12716/1001.12.04.17 (Accessed June 12th, 2019)

[39] Žuškin, S., Brčić, D., Šabalja, Đ.: A Contribution to Improving the Standards of ECDIS Training. Pomorstvo - Scientific Journal of Maritime Research, Rijeka, Croatia, 2013, Vol.27, No.1, pp. 131-148, (ISSN: 1332-0718).

[40] Žuškin, S., Brčić, D., Valčić, S.: ECDIS possibilities for BWE adoption. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 2017, Vol.11 No. 3, pp. 477-482, (ISSN: 2083-6481), DOI: 10.12716/1001.11.03.13

[41] Žuškin, S., Valčić, M., Rudan, I.: ECDIS System in Function of Sea Environment Protection. Shaping Climate Friendly Transport in Europe: Key Findings and Future Directions, (REACT 2011), University of Belgrade - The Faculty of Transport and Traffic Engineering, Belgrade, Serbia, 2011. pp. 304-310, (ISBN: 978-86-7395-282-6).

[42] Žuškin, S., Brčić, D., Kos, S.: Partial structural analysis of the ECDIS EHO research: The safety contour. Proceedings of the 7th International Conference on Maritime Transport. Barcelona: Oficina de Publicacions Academiques, Barcelona, Spain, 2016. pp. 246-264, (ISBN: 978-84-9880-591-8).

ECHOES REDUCTION DURING DIGITAL DATA TRANSMISSION IN HYDROACOUSTIC CHANNEL – LABORATORY EXPERIMENT

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Summary

The possibility of using a hydroacoustic channel for digital data transmission is very limited. This is due to the effect of multipath propagation of the emitted acoustic wave and the damping of the mechanical wave in this medium, which increase with frequency. The first of these phenomena results in inter-symbol interference disturbances in data transmission systems, including even hundreds of symbols. Due to the number of reflections and, at the same time, the long memory time of the hydroacoustic channel, it is particularly difficult to ensure communication in water of harbour areas, channels and straits with a rocky bottom etc. Therefore, our goal is to develop a method of echoes reduction in the hydroacoustic channel, which could be used in broadband underwater communication systems. The article presents researches carried out on method of echo reduction in digital data transmission in the hydroacoustic channel. The effectiveness of the method will be evaluated based on a comparison of the impulse responses of the hydroacoustic channel determined before and after the elimination of the echo. Moreover the variance of in-phase component as well as coefficient of variation will be determined for transmitted digital data and compared before and after using proposed method of echoes elimination. The researches will be carried out for different carrier frequencies of the test signals. In the research, we will use simulation methods and experimental research conducted in the laboratory conditions.

Keywords: multipath propagation, echoes reduction, data transmission, hydroacoustic channel

1. INTRODUCTION

Propagation of sound in water is accompanied by a number of physical phenomena. Most of them have a negative impact on the possibility of using a sound wave for data transmission in hydroacoustic channel. An example of these phenomena can be refractions (positive, negative or variable sign), which affects the geometric range of hydroacoustic devices. Another phenomenon is the expansion of the wave front, which reduces the signal strength along with the distance from the sound source. The resistance of the environment, which increases as the frequency of the acoustic wave increases, also reduces the power of the received signal [5, 6]. Here it should be emphasized that the higher carrier frequencies allows faster data transmission, but at the same time reduces the distance at which data can be transmitted. A serious problem, especially when it comes to underwater communication, is the multipath propagation effect. Due to the relatively long memory time of the hydroacoustic channel, it causes inter-symbol interference, which under certain conditions may prevent transmission completely. This phenomenon is particularly evident in waters with strong hydrotechnical buildings (ports, canals), rocky bottoms, shallow water, etc. The multipath propagation effect results mainly from the reflection of an elastic wave from underwater obstacles. These obstacles may be specific underwater elements (walls, pillars, etc.), but also the surface of the water, the bottom as well as sudden changes in the physical and chemical properties of the water, for example salinity or temperature. This means that apart from the original sound, the receiver also receives reflected waves (echoes) of the transmitted signal. Echoes will have a lower level due to scattering, which depends on the frequency of the transmitted wave as well as on the material, from which the obstacle is made, its location and dimensions. Nevertheless, disturbances introduced by echoes may prevent proper reception of data transmitted using a hydroacoustic channel. This problem is very serious, because while there are many devices on the market for data transmission in the hydroacoustic channel, the vast majority of them can't cope with difficult propagation conditions, e.g. ports, where the effect of multipath is strong and the number of echoes reaching the receiver is significant.

For the above reasons, the authors of the article aimed to develop a method that would allow to reduce echoes during data transmission in the hydroacoustic channel.

This article is dedicated to research carried out in area of hydroacoustic and telecommunication. It must be noted that methods of echo reduction (echo cancellation, echo suppression) are commonly used in telephony [7]. There are some reports of using this kind of signal processing in radiocommunication. In such cases, adaptive filtration [9], blind separation [3] or convolution methods with the inverse impulse response of the transmission channel [1] are most often used. These methods suffer from a one serious disadvantage i.e. the transmission channel must be stationary in a relatively long time. In the case of underwater communication, this condition can rarely be met.

The structure of the article is as follows: the first part describes in detail the method of echo reduction using cepstral analysis. Further are presented results of simulation tests, the research laboratory stand and the results obtained from the tests in laboratory conditions. At the end, the results were discussed and the conducted works were summarized as well as further research directions were indicated.

2. METHOD DESCRIPTION

We assume that as a result of multipath phenomena, in the received signal, the transmitted signal and its echoes created by reflections of transmitted signal from underwater obstacles, have been added to each other. Delay of echoes depends on length of path of propagation and amplitude depends on material of obstacle. So we can write as follow:

$$x(n) = s(n) + \sum_{i=1}^{M} \alpha_i s(n - n_i) \quad (1)$$

where: $x(n)$ – received signal, $s(n)$ – transmitted signal, n – discreet time (sample), α_i - the amplitude factor of the i-th echo, n_i – delay of the i-th echo resulting from the multipath propagation, M – the number of significant echoes of the transmitted signal.

Developed method of echoes reduction based on observation that in result of cepstral analysis there are maxima corresponding to the echoes of original signal. The cepstrum is an inverse Fourier transform, of the spectrum of the signal expressed in a logarithmic scale, what can be written as follows [2, 8, 10]:

$$C\big(x(n)\big) = F^{-1}\Big(ln\Big(F\big(x(n)\big)\Big)\Big) \quad (2)$$

where: F – Fourier transform, F^{-1} – inverse Fourier transform.

The cepstrum contains components related to the echoes-free signal (later defined as original signal), as well as the components resulting from the presence of echoes. The components derived from echoes can be filtered by linear filtration methods. According to the conducted researches, in suggested solution we propose to filtrate only this components which corresponds to the appearance of individual echoes. It must be noted that result of cepstrum analysis is symmetrical to half the length of the signal being analysed. Components connected with occurring echoes appears on left and right side of cepstrum. According to the conducted research, only components on left side should be filtered. Because the information about echoes is not known in advance so filtration is made in two steps. Firstly, there are searched components with locally maximum values in a given range (chosen so as not to delete information about the original signal). In location of selected components the cepstrum is multiplied with inversed Hanning window with a given width (width of few components). It causes zeroing components corresponding to the appearance of echoes. Such modified cepstrum will be used to reproduce the signal in the time domain. Here we use the property that the cepstrum function is a reversible function. This process can be written as follow [2, 8, 10]:

$$x(n) = C^{-1}\big(x(n)\big) = F^{-1}\left(exp\left(F\left(C\big(x(n)\big)\right)\right)\right) \quad (3)$$

Figure 1 presents a block diagram of the system performing the operation of multipath effect elimination from the input signal.

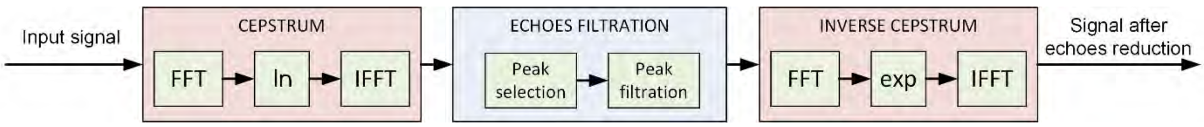

Figure 1 The block diagram of signal processing during echoes reduction

Our research confirmed that the filtration process of selected components of cepstrum should be repeated several times (in investigated cases 3 to 5 times) to get the best result.

Assessment of effectiveness of the developed method of echoes reduction will be carried out based on a comparison of channel impulse response estimates determined for the original signal (recorded) and after echoes reduction. In the impulse response of the hydroacoustic channel there are maxima, which correspond to the echoes of the transmitted signal which are reaching receiver as a result of the multipath propagation. The most important will be change of levels of significant echoes identified in channel impulse response. Estimation of hydroacoustics channel impulse response can be determined using pseudo-random binary sequence [4, 11]. The estimate of channel's impulse response can be determined using module of cross-correlation function between the pseudo-random binary sequence and the received signal brought to baseband. The cross-correlation can be calculated according to the formula:

$$R_{zy}(k) = \sum_{n=0}^{N-1-|k|} z(n)y^{*}(n-k) \quad (4)$$

where: $z(n)$ – represents a pseudo-random sequence, $y(n)$ – received signal brought to the baseband.

Based on (4) the estimation of impulse response of the hydroacoustic channel can be determined as follow [4, 11]:

$$I_R(k) = \sqrt{\left(\sum_{n=0}^{N-1-|k|} z(n)y_s^{*}(n-k)\right)^2 + \left(\sum_{n=0}^{N-1-|k|} z(n)y_c^{*}(n-k)\right)^2} \quad (5)$$

where:

$$y_s(n) = x(n)\sin(2\pi f_n n) \quad (6)$$

$$y_c(n) = x(n)\cos(2\pi f_n n) \quad (7)$$

where: f_n – carrier frequency.

During the researches, a sinusoidal signal modulated by a pseudo-random binary sequence PRBS with the use of BPSK (Binary Phase Shift Keying) modulation was used. In our research we are using Gold sequence as PRBS.

As second assessment we will use statistical parameters which characterize constellation during digital data transmission. During research we will use Binary phase-shift keying (BPSK) modulation (sometimes called phase reversal keying PRK or two phase shift keying 2PSK) which is the simplest form of phase shift keying. We will use two phases 0 and 180 degree. During demodulation each symbol can be represented by a complex number, and the constellation diagram can be regarded as a complex plain with the horizontal real axis representing the in-phase (I component) carrier (cosine wave) and vertical imaginary axis representing the quadrature (Q component) carrier (sine wave). An ideal constellation diagram for BPSK will show two position of the point representing each symbol. But, because of noises, distortion, multipath propagation, carrier frequency change etc. during passing through communication channel, the values of amplitude and phase after demodulation may differ from the correct value for each symbol. It causes that point on constellation diagram, representing received symbols, will be offset from the correct position of symbol. If the aforementioned phenomena causes a significant dispersion, it can lead to a situation in which the point representing the symbol will be in the region represented by another symbol. In this situation demodulator will misidentify that symbol what results in an error [12]. One of the measures of dispersion is variance. We will determine this value only for I axis, because of used BPSK modulation, before and after echoes reduction what should shows the influence of presented above method on the possibility of correct data reception. To calculate this parameters we will use following formulas:

$$\sigma_I^2 = \frac{1}{m}\sum_{m=0}^{M-1}(y_{Ic}(m) - \mu_I)^2 \tag{8}$$

where:

$$\mu_I = \frac{1}{m}\sum_{m=0}^{M-1} y_{Ic}(m) \tag{9}$$

$$y_{Ic}(m) = \left|\sum_{l=0}^{L-1} y_c(m+l)\right| \tag{10}$$

Where: L – length of single symbol in samples.

Moreover, we will determine coefficient of variation which is defined as the ratio of the standard deviation to the mean value:

$$v_I = \frac{\sigma_I}{\mu_I} \tag{11}$$

This coefficient will show the extent of variability in relation to the mean value. The higher the coefficient of variation, the greater the dispersion and the worse the average representing the population, and therefore constellation has a lower cognitive value.

All mentioned above parameters, estimated impulse responses and variations of in-phase components of constellation diagram as well as coefficient of variation, determined before and after echoes reduction should show the usability of the proposed echoes reduction method in hydroacoustic communication systems.

3. RESULTS OF RESEARCH

In the first stage of the research, to properly assess the correctness of the adopted solutions and to have the possibility to influence all parameters, controlled test conditions were prepared in a simulation environment. Simulation tests were carried out in the Matlab computing environment. The first task was to prepare test signal. Therefore, the results of measurement carried out under real conditions based on measurement of impulse responses of hydroacoustic channels were used [11]. For the selected estimation of impulse response the significant echoes were identified (figure 2).

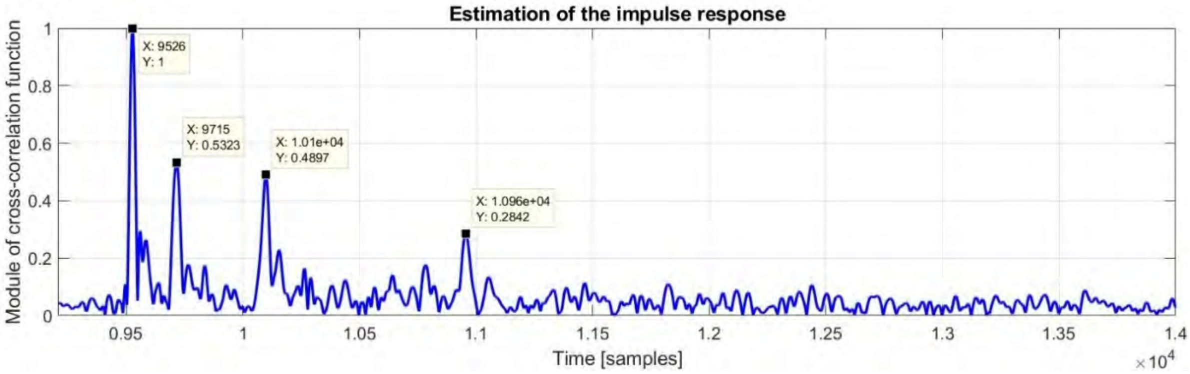

Figure 2 Estimation of impulse response of hydroacoustic channel with marked significant echoes used during signal generation in simulation researches

Knowing the delays as well as the level of the echoes amplitudes, a test signal was generated by simply summing the dispersed signals with the appropriate time delays and signal amplitudes. The signal was then subjected to an echo reduction process according to the method described above. The impulse response estimate was again determined for the result signal. Figure 3 shows the impulse response estimate before and after echo reduction.

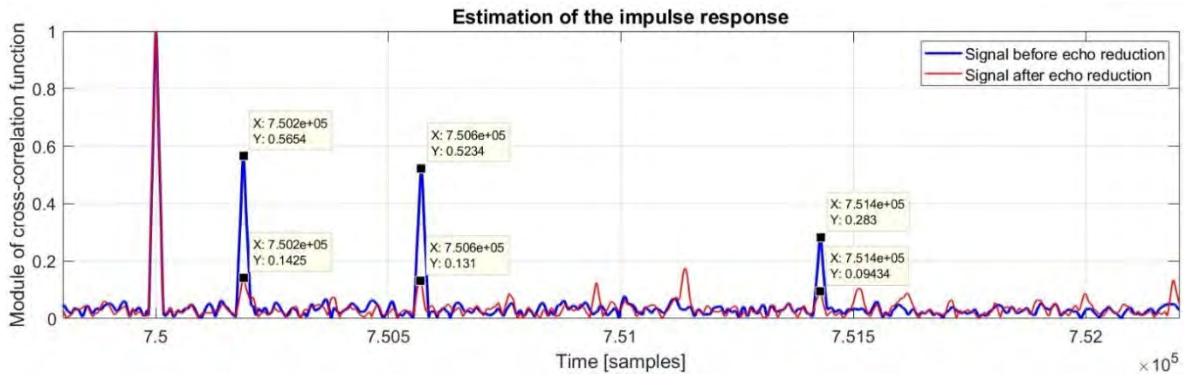

Figure 3 Estimation of impulse response for signals before and after echoes reduction

Simulation studies allows us to follow the process of reducing echoes over time. Figure 4 shows how the impulse response changes as a result of the applied method.

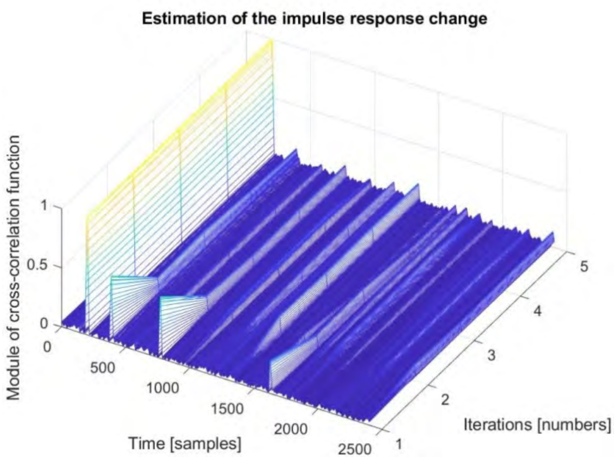

Figure 4 Changes in estimation of impulse response during echoes reduction process

As it is shown the level of significant echoes decrease 4 to 3 times relatively to signal before echoes reduction. Simulation tests were repeated for different carrier frequencies which changes in the range from 10 kHz to 150 kHz. The results obtained were similar. This allows to draw the initial conclusion that the solutions adopted in the method of echo reduction are applicable.

The next stage of the research was carried out in laboratory conditions. For this purpose, a measuring stand was prepared which consisted of the following elements: transmitting path: laptop with NI SignalExpress software, a NI USB-6259 multifunction I/O device, an Etec PA1001 power amplifier, and Reson TC4013 hydrophone; the receiving path: Reson TC4013 hydrophone, Reson EC6061 amplifier, NI-9222 voltage input module, laptop with NI SignalExpress software [4]. The researches were carried out in the water tank which had dimension of (width × length × depth) 120 × 143 × 110 cm. The used water tank is a very difficult environment for data transmission in the hydroacoustic channel. This is due to strong reflections from the boundaries of tank and its small size, which results in short times of many echoes.

In determining estimation of hydroacoustic channel impulse response we used Binary Phase Shift Keying (BPSK) modulated signals. The signal carrier frequency was changed between 10 kHz and 150 kHz and was modulated at a rate f_{symb}=25 ksymbols/sec by linear binary sequence of length 2047 bits. After recording received signal it was processed according to the described above method of echoes reduction. Figure 5 shows chosen results of estimation impulse response before and after echoes reduction. Results of tests conducted for other carrier frequency were similar.

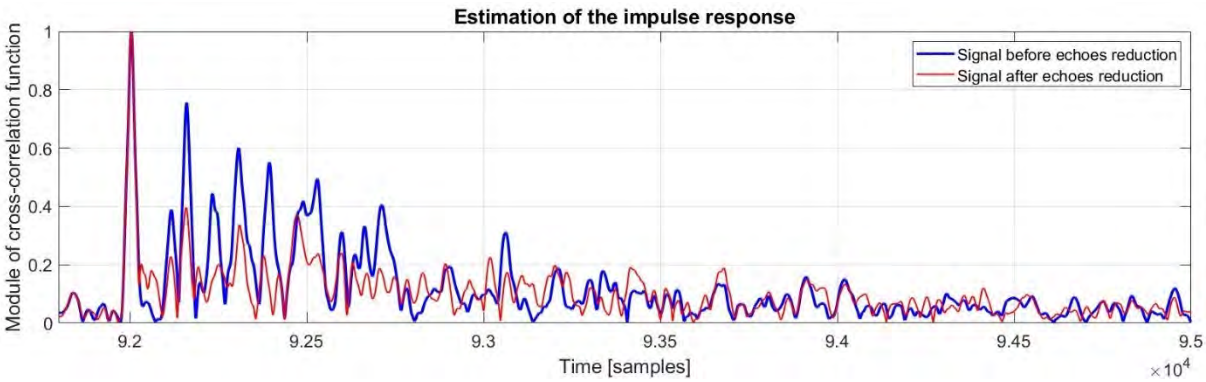

Figure 5 Estimation of impulse response for signals before and after echoes reduction during laboratory condition researches

As it is shown most of significant echoes level decrease almost 2 times. This suggests that the method works even in such difficult conditions as during laboratory tests.

In the next step of the research, the influence of the described echo reduction method on the data transmission in the hydroacoustic channel was checked. Using the same measurement system we transmitted information organized as follow: first 14 bits were set as logical ones (synchronization bits) and next 140 bits was data bits. Data were transmitted using bandwidth from 10kHz to 120kHz. The assessment of the impact of the presented method on data transmission was based on a change in the variance of the I component as well as coefficient of variation. Figure 6 and 7 presents constellation for signal transmitted at carrier frequency equal to 100kHz and two bandwidth respectively: 10kHz and 90kHz.

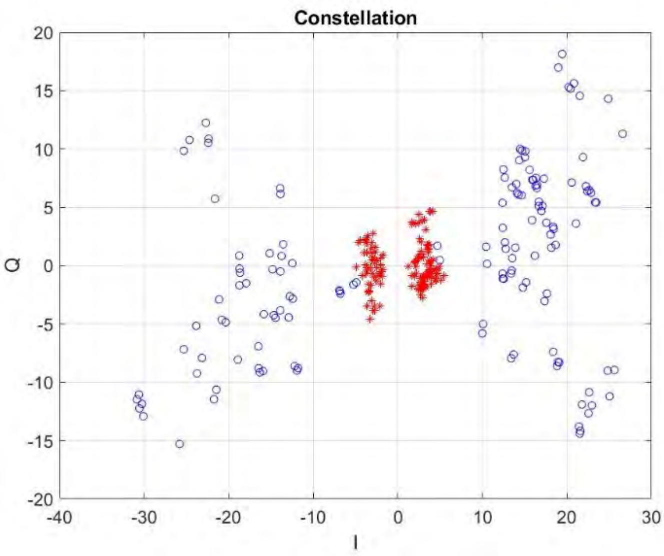

Figure 6 Constellation before (blue colour) and after (red colour) echoes reduction during laboratory condition researches for transmission of data at carrier frequency of 100kHz and bandwidth 10kHz

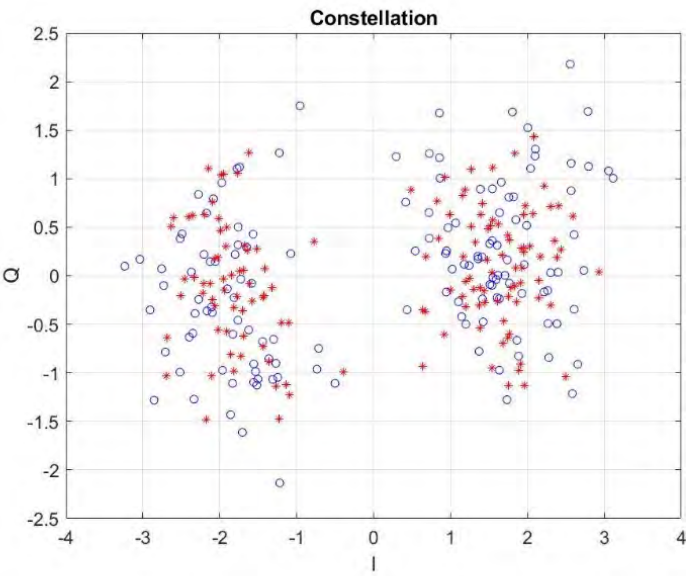

Figure 6 Constellation before (blue colour) and after (red colour) echoes reduction during laboratory condition researches for transmission of data at carrier frequency of 100kHz and bandwidth 90kHz

As it is shown in Figure 5 and 6 the value of variation for I component as well as coefficient of variation has been lowered after multipath effect elimination. In the first case (bandwidth 10kHz) variance of I component decrease form value 28.9815 to 0.6949 and coefficient of variation decrease from value 0.3186 to 0.2493. In the second case (bandwidth 90kHz) variance of I component decrease from value 0.3959 to 0.2479 and coefficient of variation decrease from value 0.3557 to 0.2901. It must be noted that for transmission made in narrow band the improvement is much better. In general, it can be said that the described above method allows to reduce the dispersion of transmitted data, which improves the ability to distinguish between logical states of transmitted information. Thanks to this, one should expect a reduction in the number of errors in the transmitted data and thus an improvement in the quality of transmission.

4. CONCLUSION

The article presents results of researches which concentrate on development and testing method of echoes reduction in signals transmitted by a hydroacoustic channel. The presence of echoes results from the occurrence of the phenomenon of multipath propagation and is undesirable for telecommunications systems operating in this environment. Long memory time of the channel causes significant inter-symbols interference.

In the described solution we used cepstral analysis to reduce echoes. We conducted studies of the developed method at the beginning in simulation conditions and then laboratory conditions close to real. Evaluation of the correctness of the echoes reduction method was performed in two stages. In the first one, we assessed the impact on the impulse response of the channel, which, among other things, allows us to identify and measure specific echoes. In this study, it is clear that the echoes have been reduced as a result of the described method. In the second stage, we used the data transmission with the simplest BPSK modulation. In this case, we assessed the impact of the method on the obtained constellation. We made the assessment of the constellation based on statistical values, i.e. the variance and the coefficient of variation. As it is shown in presented results we have achieved an improvement in the transmission quality i.e. reduced dispersion of I components, after echoes reduction. It should be noted that in the case of increasing the bandwidth in which data transmission occurs, the impact of the method on the transmission quality decreases. This may result from overlapping spectra of echoes and inability to separate them (each data packet is the resultant value of all replicas arriving during the chip's duration of the modulating signal transmitted). Conducted experiments in laboratory conditions confirmed the usability of the echo reduction method according to the described method.

Future research should concern the impact of echo cancellation parameters (number of peaks reduced in Cepstrum, number of reductions, reduction bandwidth, etc.) as well as real-time testing to confirm the suitability of this method in data transmission devices in the hydroacoustic channel.

REFERENCES

[1] Aylward R., Echo cancellation by deforming sound waves through inverse convolution, Transactions on the Built Environment, WIT Press 1997, vol 25, pp. 121-127.

[2] Childers D. G., Skinner D.P., Kemerait R. C., The Cepstrum: A Guide to Processing, Proceedings of the IEEE 1977, Vol. 65, No. 10, pp. 1428–1443.

[3] Comon P., Jutten C. (editors): Handbook of Blind Source Separation: Independent Component Analysis and Applications, Academic Press, 2010

[4] Kaczorek P., Studanski R., Zak A., Stand for determining the impulse response of a hydroacoustic channel [in Polish], Scientific Papers of the Faculty of Electrical and Control Engineering at the Gdansk University of Technology 2017, No. 57, pp. 33-36.

[5] Kochańska I., Schmidt J.H., Estimation of Coherence Bandwidth for Underwater Acoustic Communication Channel, 2018 Joint Conference – Acoustics, IEEE 2018.

[6] Kochańska I., Nissen I., Marszal J., A method for testing the wide-sense stationary uncorrelated scattering assumption fulfillment for an underwater acoustic channel, The Journal of the Acoustical Society of America 143, pp. EL116-EL120, 2018.

[7] Kosanovic B., Echo Cancellation Part 1: The Basics and Acoustic Echo Cancellation [on-line] https://www.eetimes.com/document.asp?doc_id=1277615 [access] 02.09.2019

[8] Oppenheim, A. V., Schafer, R. W., From Frequency to Quefrency: A History of the Cepstrum, IEEE Signal Processing Magazine 2004, Vol. 21, Iss. 5, pp. 95–99.

[9] Pushpalatha G. S., Mohan Kumar N.: Echo Cancellation Algorithms using Adaptive Filters: A Comparative Study, International Journal on Recent Trends in Engineering and Technology, Vol. 10, No. 2, 2014, pp. 36-43

[10] Randall R. B., A history of cepstrum analysis and its application to mechanical problems, Mechanical Systems and Signal Processing 2017, Vol. 97, pp. 3-19.

[11] Studanski R., Zak A., Results of impulse response measurements in real conditions, Journal of Marine Engineering and Technology 2017, Vol. 16, Iss. 4, pp. 337-343.

[12] Wesołowski K., Basics of digital telecommunications systems [in Polish], WKŁ Warsaw, 2006

EIGHT MARITIME LEGAL TERMS ACCORDING TO *CARRIAGE OF GOODS BY SEA ACT*; RESEARCH INTO ENGLISH LANGUAGE AND CROATIAN TRANSLATION EQUIVALENTS

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Summary

Seafaring and Maritime Law worldwide require a high level of linguistic competences in Maritime English since the majority of the documents nowadays are written in English. Croatian seafarers are global citizens whose careers will be realized aboard mainly foreign companies worldwide. Therefore, we chose twenty full-time third-year students of the Nautical Department of the University of Dubrovnik (enrolled in the academic year 2018/19) who were involved in the linguistic research. The survey was compiled by their two lecturers (one in Maritime Law, the other in Maritime English). The research took place from April 8th to 15th, 2019. The aim of the study was, to continue investigations into Maritime English i.e. specialized Maritime Law terminology. The level of the students' knowledge has usually been very satisfactory so far, due to the number of hours of English language during their previous and current education. Our aim was to collect the data and systemize them. Therefore, 8 (eight) following terms have been taken into consideration in the research: Time Charter, Voyage Charter, Carrier, Shipper, Bill of Lading, Sea Waybill, Laytime and Demurrage. By the end of the research, the results will have shown detailed definitions, translational equivalents and semantic features of the terms. Our students have shown an exceptional motivation and a great effort, necessary for their future profession. On the other hand, their lecturers have collected the data and results which will be used in improving our teaching materials for oncoming generations.

Keywords: Maritime Law, Maritime English, Nautical Department, linguistic research

1. INTRODUCTION

1.1. Notion of Maritime Property Law

Maritime property law is a system of legal norms regulating property relations in the activities at sea. Property relations refer to the relations among persons, who cooperate in a common maritime adventure.The legal basis of those relations is the contract, but the relations might occur also beyond the contract, based on the law. Maritime Property Law includes Carriage of Goods by Sea Act and other acts.

1.2. Short Account of the Development of Maritime Property Law (COGSA)

Maritime Property Law[1] has been developed parallel with the increase of seaborne trade. In the beginning, it was applied as a common law, and later on by means of codification, certain legal norms regulating this area were enacted. In the development of Maritime Law on the Dalmatian Adriatic Coast. The Statutes of Dalmatian Medieval Cities must be mentioned, especially the Statute of Dubrovnik from 1272. Dubrovnik played an important role in the development of codification. The law of the Republic of Dubrovnik, regarding maritime insurance, is considered to be the oldest law of that type in the world.

Also significant is the provision regulating load line certificates, which was adopted in 1341. However, it is well known that the first Load Line Convention was ratified in London, in only as early as 1930.

To equalize the rules of maritime property law, several international conventions were implemented.

The Conventions regulating the carriage of goods by sea will be listed chronologically.

The first Convention of this type was signed in Brussels in 1924. It is known as Bill of Lading Conventions i.e. Hague Rules. The goal of the Convention was to limit the freedom of contracting, to protect the transport user. The convention refers only to the contracts for which Bills of Lading have been issued. The Maritime Code of The Republic of Croatia is applied to all the contracts regardless Bill of Lading.

The decrease in the values of world money and the advances in transportation technology led to the necessity of revision of the Convention. Thus in 1967. The Protocol of the revision of the Hague Rules was enacted, known as Hague-Visby Rules.

Further development of commerce and seafaring led to the further necessity to revise the provisions of maritime law, especially law regarding seaborne transport, so under the guidance of the United Nations, the procedure of the revision of the existing rules started. The aim was to diminish the role of the carrier, with the users of the transport services. Thus, the famous Hamburg Rules appeared.

The significance of these Rules is the fact that they considerably and severely increase shipper's responsibility. Croatia has not ratified this Convention although some provisions were incorporated into the Maritime Code of the Republic of Croatia.

Although the unification had been the final goal, it did not happen because some countries remained obliged by the Hague Rules and other accepted the Hague-Visby Rules, and some of them ratified the Hamburg Rules.Therefore we have concluded that the unification has not been achieved.

Due to all the above mentioned, a new revision regarding carriage of goods by sea was done and consequently, in Rotterdam on the 23rd September, 2009 the Convention known as the Rotterdam Rules was signed. These Rules introduce essential news, making the Carrier considerably more responsible. They introduce electronic papers, extend the obligation of "due diligence" and incorporate the principle of "door to door". Mentioned Rules will be enforced once they have been ratified by more than twenty States.[2]

1.3. Maritime English

1.3.1. English as a *lingua franca*

The English language has long been the *lingua franca* of seafaring because the multilingual environment had required one working language. That is not the language of common people, but a specialized language for specific purposes (ESP). According to Cole and Trenker[3] (2004) there are 341 million people, who use English as a first language and around 300 million use it as a second language. They state that in 105 countries, around 50% of the world total, it has official or special status. At the same time, David Crystal (1995)

[1] Pavić, Drago (2006.) Pomorsko imovinsko pravo. Split: Književni krug pp. 100-120; 149, 156, 158
[2] Skorupan Wolff V. (2010.) Poredbena analiza Haških i Roterdamskih pravila, PPP god. 49(2010), 164, pp. 169-210.
[3] Cole, Clive and Trenker, Peter (2004) Whither Maritime English? In Retrospect and Prospect; International Maritime English Committee (16 IMLA/IMEC) pp. 22-34.

calculated that one in five of the world's population speaks English "competently" and that one in three are exposed to it daily. Great Britain as an insular country had always had ambitions to spread its trade worldwide. As the dominating partner, they would then expect the local inhabitants to communicate in English if they wished to do business with the British vessels. Fred Weeks, the first president of the International Maritime English Conference (IMEC) suggested that "this probably formed the basis of the pre-eminent usage of the English language Bills of Lading and Charter Parties." The expansion of the English language was dramatic, especially after the Second World War, due to the British-American scientific and technological progress and dominant trade and commerce which influenced all other aspects of life.

1.3.2. Linguistic features of Maritime English

Boris Pritchard defined in 2011[4] maritime legal texts as specific type of legal instruments and documents with binding force in national legislation and international maritime law. Those texts could be: international conventions, treaties, regulations, rules, contracts and official documents.

Not many authors discussed the qualities and features of Maritime English (ME) from the linguistic point of view. However, in 2014, in Canada, Daniele Franceschi[5] published in the International Journal of English Linguistics the article titled *The Features of Maritime English Discourse*. The paper refers to the previous studies in ME by the following authors: Maurizio Gotti (2005), Peter Trenker (2000), N. Demydenko (2012), Boris Pritchard (1999, 2003, 2011), et al.

Franceschi studied the written texts which are part of the following semantic areas: maritime engineering, marine electronics, and maritime law. The spoken discourse was analyzed too, but it is not relevant for this particular paper. We focused on maritime law written text based on the analysis of the corpus of one issue of the *Journal of International Maritime Law*. The author states that Maritime English in the domain of maritime law is the most specialized one, which has been proven by the existence of glossaries and dictionaries in this specific field. He gives an example of the word *arrest* which refers to the act of taking a person into custody, but in maritime law, it specifically indicates seizing and holding a ship under lawful authority. At the same time, the expression *lay days* meaning allowed period for loading/unloading the cargo without the payment and this expression does not exist at all, in common everyday speech. He also states that maritime law domain applies a formal style, which is evident by Latin-based words (e.g. *salvage*). Lexical redundancy is also particularly common as in the following sentence in which the word *mortgage* is repeated four times.

In The Betty Ott v. General Bills Ltd., 43 New Zealand's Court of Appeal also invoked The Halcyon Isle in refusing to recognize an Australian ship mortgage as equivalent to ship mortgage registered in New Zealand, simply because the mortgage had not been registered in New Zealand (and this, despite the very similar terms and conditions governing ship mortgages and their registration in Australia). (Daniele Franceschi, page 80)

Lexical redundancy often results in doublets (e.g. *terms and conditions*), whose purpose is to reinforce and emphasize a certain concept. Finally, antiquated vocabulary is normal in maritime law terminology (e.g. *herein*, *therein*, *witnesseth*, etc.) An authoritative tone of maritime law texts has usually been achieved by the adoption of full Latin phrases (e.g. *res derelicatae* = abandoned marine property) and by the use of fixed expressions (e.g. *as the content may require, unless otherwise defined,* etc.) Maritime law texts tend to be heavy and they also contain a lot of passive forms and expressions involving the use of impersonal *you* which contribute considerably to neutrality, formality, and clarity. The author concludes that this special language or rather languages should be viewed as a multi-faceted type of specialized discourse and that the reader of Maritime English texts is required to have a multidisciplinary and integrated knowledge of the maritime field.

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[4] Pritchard, Boris (2011) Pomorski institucionalni vokabular: neka terminološka pitanja U *Hrvatski na putu u EU Terminološki ogledi*, Uredila Maja Bratanić, Zagreb: Institut za hrvatski jezik i jezikoslovlje i Hrvatska sveučilišna naklada pp. 151-189.
[5]Franceschi, Daniele (2014) *The Features of Maritime English Discourse*. International Journal of English Linguistics, Vol.4 No2; pp. 80-87.

Sandra Tominac-Coslovich and Mirjana Borucinsky in 2015 discussed the grammatical level of maritime law institutional texts saying that in those types of texts one could find a limited usage of tenses, reduced negations of the sentences (e.g. unnecessary, inefficient, none) and special usage of modal auxiliaries (e.g. shall, for expressing obligation).[6]

1.4. Development of Maritime Croatian

The Croats have been present on the Adriatic coast and in the Mediterranean for a thousand years. The Croatian maritime vocabulary is connected with the historic tradition of the Croats in the Adriatic.[7] Etymologically speaking, maritime vocabulary is a spectrum of different language origins: general Slavic, Greek, Latin, Dalmatian, Arabian, Turkish and finally numerous Romance (mainly Italian) origin terms. In the development of the Croatian maritime terminology, an important role was played by the maritime schools on our coast: the first one in Perast, mentioned as early as in the 16th century, then the Nautical School of Kotor, which was opened in the 19th century, and the Nautical School of Bakar and Dubrovnik (1852)[8]

The Croatian nation could proudly say that it had its vocabulary of the Croatian language as early as in the 16th century. It was compiled by Faust Vrančić (1551-1617) from Šibenik. Then, there was another one by Matija Alberti (1561- 1623) from Split. One century later, Pavao Ritter Vitezović (1652-1713) compiled the vocabulary which is still in manuscript. It was thoroughly studied by Blaž Jurišić. It contained 2,253 maritime-related terms. It was specific for distinguishing general from a specific maritime vocabulary. Ardelio Della Bella (1655-1737) also published a specific vocabulary. In the 18th century, Joakim Stulli, a Jesuit of Dubrovnik, published *Croatian-Italian-Latin Vocabulary* in three versions. This vocabulary is considered to be the synthesis of the linguistic heritage of the literature of Dubrovnik and the mirror of the way of life in the Republic of Dubrovnik. During the 19th century, Blaž Jurišić (1891-1974) published the dictionary by Jakov Antun Mikoč, which had been in a manuscript. Božo Babić also based his studies on this vocabulary.

Mato Vodopić (1816-1893), who was the bishop of Dubrovnik and writer of a famous short-story titled *Tužna Jele* (1866), adopted original Croatian maritime vocabulary (about 80 words clarified in footnotes) with recommendations to continue the research into Croatian lexicology.

Božo Babić (1840-1912) contributed considerably to the development of Croatian terminology.[9] He was the officer aboard an Austro-Hungarian vessel, and on his voyage from Klek to Trpanj, according to his diary, he decided to collect Croatian words and eliminate foreign expressions. He succeeded in his intention. He published 6 booklets of maritime-related terminology, by which he fought against Italian phrases, wanting to eliminate them. He is considered to be the founder of the Croatian maritime-related terminology by means of his persistent work. Initially he worked in maritime education and later, he published lexicographic editions in the Croatian maritime terminology. He also collected the terms from his region as well as from other parts of the Croatian coast. Juraj Carić published *Slike iz pomorskog života* in 1884. It is a very significant piece because it reflects his consistency in the usage of the Croatian spoken traditional terminology. It is also considered to be a valuable maritime travelogue.

After World War I, when „Our Sea" started to be published, a fierce discussion regarding the Croatian maritime terminology began between Juraj Carić and Rudolf Crnić in our journal. On one hand, Carić advocated the view that *Italian phrases* should be used and criticized the work of the Bakar School, which wanted to eliminate Italian phrases. He formed his opinion according to Pero Budmani (1835-1914) philologist from Dubrovnik and editor of the Vocabulary of Jugoslav Academy of Science and Arts. Crnić

[6] Tominac-Coslovich Sandra & Borucinsky, Mirjana (2015) Sintaktički diskontinuitet u izvornom pomorskom pravnom tekstu na engleskom jeziku i u njegovu prijevodu na hrvatski. U *Od Šuleka do Schengena*: *Terminološki, terminografski i prijevodni aspekti jezika struke* Urednici: Maja Bratanić, Ivana Brač i Boris Pritchard; Zagreb: Institut za hrvatski jezik i jezikoslovlje. pp. 283-300.
[7] Vidović, Radovan (1993) Jadranske leksičke studije; Split: Književni Krug. pp. 215-246.
[8] Carić, Tonka (1989) Engleski jezik u nastavi u našem pomorskom školstvu, magistarski rad, Sveučilište u Zagrebu, Interuniverzitetski centar za postdiplomske studije Dubrovnik
[9] Nosić, Milan (2007) Pomorski leksikograf Božo Babić, Rijeka: Maveda i HFDR

wanted even to penalize the usage of foreign terminology, but the real spoken language of Merchant Marine officers remained unchanged.

2. DATA

Maritime Department of the University of Dubrovnik has *Maritime English* as an obligatory course, in the semesters 1-5 according to the Syllabus adopted by the Senate of the University of Dubrovnik in the year 2014. within the number of hours per week: **1st** semester: 2 lectures and 2 exercises 2nd semester: 2 lectures and 2 exercises; 3rd semester: 2 lectures and 2 exercises; 4th semester 2 lectures and 2 exercises; and 5th semester 1 lecture and 2 exercises. On the other hand, the course in *Maritime Law* as a subject is present in the first year as 4 lectures per week during the 1st semester and *Maritime Property Law* lectures are structured 3 lectures per week - 6th semester.

The research which preceded this paper was meant to establish the level of knowledge of maritime-property-law-related terms and to find adequate Croatian translational equivalents. Therefore, three survey papers were prepared. The Survey paper No1. contained eight (8) maritime law terms in English: Time Charter; Voyage Charter; Carrier; Shipper; Bill of Lading; Sea Waybill; Laytime and Demurrage. Students were asked to give translational equivalents in Croatian. The selection of the terms was done according to Pavić (2006, pp. 100-120). We limited our choice only to those terms which were also found in William Tetley's Glossary of Maritime Law Terms. The Survey paper No.2. contained a questionnaire, which required from the students to put on the paper an exact letter of definition from the Survey paper number No.3. The students showed great interest and enthusiasm in solving the quiz, which they were offered. The third survey paper contained the definitions of eight terms out of William Tetley's Glossary. The definitions of those terms were limited to one to three sentences. The selection of the terms was randomly done and we are conscious that the choice is not comprehensive and representative. This has been just an attempt to test our students and to raise their (and our) level of consciousness regarding maritime property law terminology.

3. RESULTS

Survey paper No.1 required from the examinees to translate eight (8) terms from Maritime English into Maritime Croatian. Eleven (11) out of the expected twenty (20) students participated in the survey.

Only one (1) of them, submitted the paper with eight (8) correct answers. Six (6) candidates submitted the paper with seven (7) correct answers. Two (2) students gave six (6) correct answers. One (1) student answered correctly with three (3) answers and one (1) student with two (2) correct answers. The mistakes were related to exact Croatian translation equivalents.

According to Drago Pavić's definitions, translational equivalents should be:

1. Time Charter - *Brodarski ugovor na vrijeme*
2. Voyage Charter - *Brodarski ugovor za putovanje*
3. Carrier - *Prijevoznik*
4. Shipper - *Krcatelj*
5. Bill of Lading - *Teretnica*
6. Sea Waybill - *Pomorski teretni list*
7. Laytime - *Vrijeme stojnica*
8. Demurrage - *Prekostojnice*

Instead of *Brodarski govor na vrijeme*, students used the following terms: *Brodski ugovor na vrijeme, Ugovor na vrijeme, Brod se daje u zakup na vrijeme, Brodski najam na vrijeme*. Two the students provided exact answers as mentioned above. Instead of *Brodarski ugovor za putovanje* students offered the following terms: *Ugovor na putovanje, Brodski najam na putovanje, Ugovor o putovanju, Brod se daje u zakup na putovanje,* *Brodski ugovor na jedno ili više uzastopnih putovanja* Instead of *Prijevoznik* students used: *Prijevozitelj*, *Prevozitelj*, *Osoba koja prevozi teret*. The term *Shipper* is translated as following: *Brodar*, *Nositelj pomorskog podhvata* or *Krcatelj.* The term *Bill of Lading* was translated as *Teretnica* in all cases. The term *Sea Waybill* was translated as (*Pomorski*) *teretni list*. The term *Laytime* was translated as *Stojnica* or *Stojnice*.

Finally, the term *Demurrage* was translated either as *Vozarina* or *Ležarina.* On the other hand, the comprehension of maritime-property-law-related terms (Survey paper No. 2.) was very successful (joining definitions to the terms), and students showed the high level of knowledge of the provided terminology (Survey paper No. 3.). About 70 % of the answers were correct. This has been ascribed to their intrinsic motivation in the subject matter as well as to the previous number of hours, both in Maritime Law and Maritime English. International maritime law has always been a very attractive subject worldwide for seafarers, economists, and jurists.

Similar sociolinguistic research among the students of Nautical Department of the University of Dubrovnik was carried out in 2018 during regular lectures in the first year, by the same authors. It has been established that the majority of our students are citizens of the Republic of Croatia. A small percentage come from Bosnia and Herzegovina. They finished their elementary schools mainly in Dubrovnik-Neretva County (towns: Dubrovnik, Mokošica, Župa Dubrovačka, Korčula, Šipan, Ston, Gruda). It is interesting to add that there are candidates, who attended their elementary school in the following places: Omiš, Jesenice, Pakrac, Livno, Podgora, Kaštel Stari, Zagreb and Staševica. After elementary school, they decided to study at Nautical High Schools on the Adratic Coast which have a very long tradition: Pomorsko-tehnička škola Dubrovnik, Pomorska srednja škola Bakar, Pomorska škola Split, Pomorska škola Korčula. This is indicating and interesting because all the students are of the same competences in the English language when they start their University Nautical Studies i.e. their level of knowledge is homogenous and equal. Therefore, we can justifiably say, that they study Maritime English and not general English.Therefore we renamed the subject as from the academic year 2018/19.

The tradition of studying the English language in Dubrovnik has a long history.[10] It was recordered that as early as in 1852 in Nautika, at Brsalje in Dubrovnik, the English language as an obligatory subject was introduced in the Curriculum of the School. At that time, there were no professors of English, and the lessons were led by Gjuro Margetić, Master Mariner, who obtained proficient knowledge in English by travelling to America. The necessity to know and teach English was very early recognized and adopted by the authorities of the Dubrovnik Nautical School. The professors of the Bakar Nautical School of the time were very prominent ones: Alexander Lochmer and Milan Drvodelić, who later were founders of the English Language and Literature Department of the University of Zagreb. Thus, maritime education contributed greatly to the introduction of the English language into Croatian education and culture.

This year, the centennial of the beginning of "Our Sea" scientific journal for seafaring is being celebrated and at the same time, the sixtieth anniversary of Nautical Department of the University of Dubrovnik. It is the oldest Department of the University, which passed several transformations from the organizational point of view. Master Mariners all over the world are our alumni. They represent our tradition, honour, pride, and knowledge.

4. INSTEAD OF CONCLUSION

The goal of the research was to determine the level of knowledge in maritime legal terminology. The authors prepared the Survey containing three papers in which there were provided eight (8) maritime property legal institutional terms. The target group were the students of the third year – summer term of the Nautical Department. There were 18 full-time and 15 part-time students. The survey was carried out among 11 students. The results have shown that out of 11 candidates, one student achieved excellent score, six of them

[10] Carić, Tonka (1989) Engleski jezik u nastavi u našem pomorskom školstvu, magistarski rad, Sveučilište u Zagrebu, Interuniverzitetski centar za postdiplomske studije Dubrovnik

very good, two of them good and one failed. In the remaining two survey papers, which required checking comprehension of the terminology, the examinees were more successful, having achieved 70% correctness. The results of the survey have proven to the professors in Maritime Law and Maritime English that our students are competent and knowledgable in those scientific areas. We will use them as guidelines for teaching future generations of students.

REFERENCES

1. Borucinsky, Mirjana & Sandra Tominac Coslovich (2012)"Corpus –based Analysis of Participle Clauses in English and Croatian Maritime Institutional Texts", *Strani jezici*, 41, 2:115-139.
2. Brlek, Mijo (1987.) Leksikograf Joakim Stulli (1730-1817) Djela Jugoslavenske Akademije znanosti i umjetnosti, Razred za filološke znanosti, Knjiga 60, Zagreb
3. Brlek, Mijo (1980) Pogled na pomorsku terminologiju Joakima Stullija, dubrovačkog leksikografa u povodu 250. obljetnice rođenja, Naše more
4. Carić, Tonka (1989) Engleski jezik u nastavi u našem pomorskom školstvu, magistarski rad, Sveučilište u Zagrebu, Interuniverzitetski centar za postdiplomske studije Dubrovnik
5. Carriage of Goods by Sea Act (COGSA), Wikipedia accessed on July 2nd 2019.
6. Cole, Clive and Trenker, Peter (2004) Whither Maritime English? In Retrospect and Prospect; International Maritime English Committee 16 IMLA/IMEC) pp. 22-34.
7. Dragojević, Lia (2014) Sociolingvističke posebnosti jezika i dijalekta pomorske struke –p(r)oučavanje engleskog i hrvatskog: U *Standardni jezici i sociolekti u 21. stoljeću,* Zbornik radova s međunarodnoga znanstvenoga skupa Hrvatskoga društva za primijenjenu lingvistiku održanog 18. do 20. travnja 2013. u Dubrovniku; uredili Anita Peti-Stantić, Mateusz-Milan Stanojević i Goranka Antunović. Zagreb: Srednja Europa i Hrvatsko društvo za primijenjenu lingvistiku. pp. 195- 209.
8. Franceschi, Daniele (2014) *The Features of Maritime English Discourse*. Internatioal Journal of English Linguistics, Vol.4 No2; pp 80-87.
9. G. A. M. E. (Gesellschaft für Ausbildung in Maritimem Englisch e.V. = Association for Maritime English, Bremen, Deutschland) in cooperation with the Faculty of Maritime Studies, University of Split; Split, Faculty of Maritime Studies, Workshop titled "Maritime Legal Terminology", September 27th – 29th 2017(Local organizer: Adelija Čulić-Viskota)
10. Milošević-Pujo Branka (2004) Ugovor o prijevozu putnika i njihove prtljage morem, zbornik radova Pravnog fakulteta u Splitu, br. 1-2/2004.
11. Milošević-Pujo, Branka (1995) Ugovor o time charteru i ugovor o zakupu broda te njihov međusobni odnos „Naše more", 42 (1995.), (1-2); pp. 65-70
12. Milošević-Pujo, Branka (1998) Ugovor o pomorskom osiguranju s osvrtom na odredbe Pomorskog zakonika Republike Hrvatske „Naše more", 45 (1998.), (1-2); pp. 73-76
13. Nosić, Milan (2007) Pomorski leksikograf Božo Babić, Rijeka: Maveda i HFDR
14. Pavić, Drago (2006) Pomorsko imovinsko pravo. Split: Književni krug pp. 100-120; 149, 156, 158
15. Pritchard, Boris (2011) Pomorski institucionalni vokabular: neka terminološka pitanja U *Hrvatski na putu u EU Terminološki ogledi*, Uredila Maja Bratanić, Zagreb: Institut za hrvatski jezik i jezikoslovlje i Hrvatska sveučilišna naklada pp. 151-189.
16. Skorupan-Wolff Vesna (2010) Poredbena analiza Haških i Roterdamskih pravila, PPP god. 49(2010), 164, pp. 169-210.
17. Tominac-Coslovich Sandra & Borucinsky, Mirjana (2015) Sintaktički diskontinuitet u izvornom pomorskom pravnom tekstu na engleskom jeziku i u njegovu prijevodu na hrvatski. U *Od Šuleka do Schengena*: *Terminološki, terminografski i prijevodni aspekti jezika struke* Urednici: Maja Bratanić, Ivana Brač i Boris Pritchard; Zagreb: Institut za hrvatski jezik i jezikoslovlje. pp. 283-300.
18. Tetley, William (Q.C.) 2004 *Glossary of Maritime Law Terms*
19. http:/www.mcgill.ca/maritimelaw/glossaries/maritime (accessed July 2nd 2019)
20. Vidović, Radovan (1993) Jadranske leksičke studije; Split: Književni krug. pp.215-246.

SUPPLEMENT

United Nations Convention on the Carriage of Goods by Sea, 1978

PREAMBLE

THE STATES PARTIES TO THIS CONVENTION,

HAVING RECOGNIZED the desirability of determining by agreement certain rules relating to the carriage of goods by sea,

HAVE DECIDED to conclude a convention for this purpose and have thereto agreed as follows:

PART I. GENERAL PROVISIONS

Article 1. Definitions

In this Convention:

1. "Carrier" means any person by whom or in whose name a contract of carriage of goods by sea has been concluded with a shipper.

2. "Actual carrier" means any person to whom the performance of the carriage of the goods, or of part of the carriage, has been entrusted by the carrier, and includes any other person to whom such performance has been entrusted.

3. "Shipper" means any person by whom or in whose name or on whose behalf a contract of carriage of goods by sea has been concluded with a carrier, or any person by whom or in whose name or on whose behalf the goods are actually delivered to the carrier in relation to the contract of carriage by sea.

4. "Consignee" means the person entitled to take delivery of the goods.

5. "Goods" includes live animals; where the goods are consolidated in a container, pallet or similar article of transport or where they are packed, "goods" includes such article of transport or packaging if supplied by the shipper.

6. "Contract of carriage by sea" means any contract whereby the carrier undertakes against payment of freight to carry goods by sea from one port to another; however, a contract which involves carriage by sea and also carriage by some other means is deemed to be a contract of carriage by sea for the purposes of this Convention only in so far as it relates to the carriage by sea.

7. "Bill of lading" means a document which evidences a contract of carriage by sea and the taking over or loading of the goods by the carrier, and by which the carrier undertakes to deliver the goods against surrender of the document. A provision in the document that the goods are to be delivered to the order of a named person, or to order, or to bearer, constitutes such an undertaking.

8. "Writing" includes, *inter alia,* telegram and telex.

ANALYSIS OF THE EFFECTS OF LOW-SULFUR FUELS ON THE CYLINDER LINER LUBRICATION IN THE MARINE LOW-SPEED TWO-STROKE DIESEL ENGINE

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Summary

The purpose of this paper is to analyze and describe the problems occurring when using low-sulfur fuel oils in the marine low-speed two-stroke diesel engine operation, as well as the measures taken to prevent damage to the individual engine components. The paper discusses the effects of low-sulfur fuels on marine diesel engine operation and examines the effects of low-sulfur fuels on the cylinder liner lubrication in the marine slow-speed two-stroke diesel engine and the differences in performance between common cylinder oils having the base number *BN70* and the *BN40* oils having the low *BN* prepared for operation with low-sulfur fuels, according to [2], [8]. Requirements for reducing *SOx* emissions from the ship exhaust systems in certain areas of navigation have resulted in using low-sulfur fuel oils in diesel engine operation. The use of heavy fuel oil *HFO* with high sulfur content has become unacceptable after the global introduction of Annex VI of the *International Convention for the Prevention of Pollution from Ships MARPOL 73/78*, the designation of some marine areas as particularly sensitive areas *Emission Control Areas - ECA*, and the implementation of monitoring the exhaust emissions from ships in *ECAs*. Maximum allowed sulfur content in fuel in European *ECAs* amounts to 0.1 % for ships in ports and all inland waterways across the European Union, whereas *California Air Resources Board CARB* applies the regulation limiting the sulfur content in fuel to 0.1 % within 24 nautical miles of the California's coastline, according to [2], [3].

Keywords: low-sulfur fuel, lubrication, cylinder liner, lubricator, viscosity.

1. INTRODUCTION

A critical function of any cylinder oil is sulfuric acid neutralization. Combustion converts the sulfur contained in fuel into sulfur dioxide gas. Some of this gas turns into sulfuric acid that causes cylinder liner corrosion and results in wear. The chemical composition of cylinder oils is designed to provide them with high alkalinity so as to neutralize the effects of sulfuric acid and to prevent corrosion as efficiently as possible. Faster neutralization rates are considered more effective for preventing corrosion.

From the standpoint of maintaining the cylinders clean and preventing the cylinder wear at low temperatures, the cylinder oil base numbers *BN* tend to increase progressively, so that today the common *BN* is 70, according to [9].

On the other hand, the environmental concern has encouraged the International Maritime Organization *IMO* and other regulatory bodies in many countries to introduce the regulations on controlling the levels of harmful exhaust emissions from ship engines, in particular with reference to sulfur oxides *SOx* and nitrogen oxides *NOx*. The use of low-sulfur fuels has also become compulsory in some waters, thus additionally increasing the demand for cylinder oils that are compatible with low-sulfur fuel oils.

In addition to low temperature corrosion, the cylinder liner is also exposed to high temperature corrosion during fuel combustion, when sulfur oxidizes to form SO_3 due to metal catalysts. At 200ºC and above, SO_3 reacts with oil adhering to the liner, creating lacquering effects across the walls. Various additives are added to the cylinder oil in order to neutralize the corrosive action of the generated acids in the combustion chamber of the marine low-speed two-stroke diesel engine, according to [9], [6]. Additives neutralize sulfuric acid during lubrication.

The neutralization of the sulfuric acid, formed by combustion, is taken care of by an alkaline reserve in the lubricants; its value is determined by the content of potassium hydroxide needed for acid neutralization mg KOH/g in the oil and is expressed as the oil's total base number *TBN*.

Annex *VI* of the *IMO MARPOL 73/78* Convention was adopted in 1997 and entered into force in 2005. The regulations related to *SOx* were described in Regulations 14 and 18.

According to these regulations, the sulfur content is globally limited to 4.5% and below, whereas in *SOx* Emission Control Areas *SECA*, such as the Baltic Sea and the North Sea, the sulfur content is limited to 1.5% and below, according to [2], [3].

At the 57th session of Marine Environment Protection Committee *MEPC 57* of the *IMO*, held in April 2008, a proposal to review *SOx* controls was studied. The agreement was reached on the proposal to control *SOx*, by limiting sulfur in fuel oil to 0.1% in 2015 in Emission Control Areas (*ECA*) and by reducing it to below 0.5% in 2020/2025 in globally. National laws were ratified in February 2004 to conform to Annex VI. The *EU* Directive established detailed regulations related to sulfur content in fuel oils in Europe, while similar regulations were established by the California Air Resources Board in the *USA*, the Los Angeles Port Authority and the Long Beach Port Authority.

At the *MEPC 57* it was also agreed that the requirements for properties of fuel oils will not apply only to the sulfur content as regulated by Annex *VI*, but also to other fuel properties affecting the safety of the ship and the environment.

The *MEPC 57* approved the proposal to reduce the existing control value [g/kWh] from 15.5% to 21.8% according to the rated engine speed [rpm] as from 2011. The proposal referring to newly built ships was agreed upon at the 12th Meeting of the Bulk Liquid and Gas Sub-Committee *BLG12* held in February 2008. The *BLG12* Sub-Committee approved the draft proposed by Japan, to reduce the existing control value by 80% in specific sea areas, according to [2], [3].

2. ANALYSIS OF THE EFFECTS OF LOW-SULFUR FUELS ON THE CYLINDER LINER LUBRICATION IN THE MARINE LOW-SPEED TWO-STROKE DIESEL ENGINE

2.1. Problem of liner *lacquering* when using low-sulfur fuel oil

Lacquering is a coloring effect due to black fuel oil without any effect of wear or quantity of lubricating oil consumed. Since anti-polishing rings came into use in 1990s, oxides of the piston crown and unburnt oil have been prevented from rubbing against the cylinder liner, and the coloring effect has been reduced considerably.

The problem of liner lacquering is a cause for concern when using low-sulfur fuel oil *LSFO* as it is harder to maintain the necessary lubricating oil film across the surface of the liner. This may lead to increased oil consumption. However, the process of lacquering ceases when the engine is switched back to *HFO*. The use of high-quality lubricating oil with improved thermal stability at high temperatures reduces the effects of fuel and the effects of flame on the cylinder liner surface, according to [2], [7].

Although the issues regarding the abnormal wear of piston rings, scuffing, high temperature corrosion and the use of low-sulfur heavy fuel oils *LSHFO* have been highlighted for a long time, comprehensive solutions related to the effects of sulfur content in the fuel on the combustion process have not been found so far, according to [2], [11].

2.2. Effects of low-sulfur fuel on the cylinder liner lubrication

Sulfur in the fuel burns and converts to a moderate amount of sulfuric acid which, when meeting the contact surface, minutely corrodes the piston rings and the liner (*micro corrosion)*, so that the contact surface becomes smooth. Consequently, the lubricating oil film can be easily retained, and the contact during a long period of operation is enhanced.

When using fuel oil with the sulfur content that generates moderate corrosion, the edges of sharp grooves of the scratches on the cylinder liner caused by fluid catalytic cracking *FCC* fines become rounded due to micro-corrosion and the oil film does not get broken.

On the contrary, if *LSHFO* is used in a cylinder liner containing a number of tiny longitudinal scratches that have occurred due to *FCC* fines, the edges of grooves remain sharp when there is no corrosion, and this may eventually result in the destruction of the oil film.

Calcium compounds, which are the main components of the base number *BN* of cylinder oil, react with sulfur compounds such as SO_2 in combustion gases, and form calcium sulphate $CaSO_4$.

This reaction suppresses the corrosion of the cylinder liner initiated by sulfur compound. However, if *LSHFO* is used and the use of cylinder oil of the normal high *BN* 70 to 80 continues, calcium oxide *CaO* is formed due to excessive *BN*. Abnormal deposits stick to the piston rings, shrink and harden. As *CaO* is harder than $CaSO_4$, excessive deposits of *CaO* may result in abnormal wear of the piston and cylinder liner. In order to prevent excessive deposits when using *LSFO*, it is necessary to carefully observe the condition of the cylinder liner and piston rings, according to [2], [7], [4].

The components of *FCC* catalytic fines are aluminium oxide Al_2O_3 and silicon oxide SiO_2, forming a very hard ceramic. The diameter of *FCC* fines included in fuel oil ranges between several microns to 100 microns, but the size frequently observed on the cylinder liner surface with abnormal wear is in the range of 10 to 15 microns. As the thickness of the cylinder oil film is smaller, issues of the oil film retention arise.

Very hard *FCC* catalyst residues enter the contact surface of the cylinder liner and piston rings, causing scratches on both the liner and the rings.

These are longitudinal scratches that are perpendicular to the piston rings that serve as a seal. The scratches easily allow high pressure and high temperature combustion gas to blow by between the piston and the liner. A large number of scratches are likely to cause scuffing.

When normal cylinder oil having *BN* 70-80 is used together with *LSFO* having the sulfur content of 1-1.5%, the residual *BN* in the cylinder oil drain becomes higher than that used in high-sulfur fuels. As a result, the *BN* of the crankcase system oil increases, depending on the *LSFO* usage time, according to [2], [4], [5].

When the normal sulfur content in fuel is 1-1.5% m/m, the use of *BN* 70-80 can be resumed and operating conditions should be carefully monitored. When the normal sulfur content in fuel is lower than 1.0 % m/m and resulting in certain difficulties in engine operation, changing over to the cylinder oil with lower *BN* should be considered. In the engines with the cylinder liner temperature set to a high level, *BN* 50 cylinder oil can be used for the fuel having the sulfur content of 2-2.5%, according to [2], [5].

If normal *BN* 70-80 cylinder oil is continuously used when using *LSFO*, serious problems in cylinder lubrication may occur. Excess *BN* (additive) is generated for low sulfur content. Consequently, excess *BN* generates calcium oxide deposits which shrink and harden. These hardened deposits rub against the cylinder liner surface which gets abraded and, at the same time, the oil film is broken. In severe cases, scuffing occurs when the deposits on the piston crown build up enough to cause liner polishing.

Several oil manufacturers offer *BN* 40 or 60 cylinder oils suitable for *LSFO*. If the additive amount is merely reduced in low *BN* cylinder oil, it is likely to cause problems. Therefore, its manufacturing method is not simple. *BN* also has detergent performance. So, if *BN* is reduced, the detergent performance reduces accordingly. This increases the piston fouling due to the processes of combustion and oxidation, according to [2], [3], [8].

BN 70 oil may vary with the manufacturer and the combination of additives, but the performance of this oil is basically the same. As for the base number *BN* in cylinder oils having low *BN*, it is considered that *BN* 40 is the most common although there are also *BN* 50 oils in use, so that the optimum *BN* value is still under discussion, according to [8].

2.3. Scuffing effects

Scuffing, i.e. adhesive wear, is a phenomenon associated with thinning and breaking of the lubricating oil film on the cylinder liner surface. When the oil film is destroyed or degraded, the piston ring comes in metallic contact with the cylinder liner and the two metal surfaces adhere one to another. Then the temperature of the liner surface increases due to friction. Scuffing, which is the cause of abnormal wear of the cylinder liner and piston rings, occurs in a relatively short time, but is a kind of precursor phenomenon that can be predicted by observing its symptoms. Before scuffing occurs, the lubricating oil film of the cylinder liner starts to break and to form again repetitively. The temperature of the cylinder liner repetitively rises and falls to its initial temperature over the 10 to 20 minute intervals. The observed and recorded oscillation has a saw-toothed waveform. When this typical phenomenon is detected and if immediate measures such as reducing the engine load or increasing the lubricating oil quantity are taken, then the process can be postponed or prevented. In addition to temperature monitoring, the occurrence of scuffing is prevented by the newly-developed systems that emit alarm when a waveform indicates the above symptoms, according to [2].

For quite a long time, ship operators and engine makers have been addressing the issue of scuffing of the inner surface of the cylinder liner in low-speed prime movers. It has been established that the damage occurs due to poor performance of the lubricating oil, fuel oil characteristics, torque change, adverse sea conditions, poor engine maintenance, poor choice of material, etc. The trouble is that the scuffing phenomenon occurs fast, it cannot be always accurately predicted, and the ship operator is forced to bear the costs of repair and delay.

Over the last decades, the marine low-speed two-stroke diesel engines have become more powerful and more complex. At the same time, the maintenance intervals have become longer and the maintenance quality lower. On the other hand, the shipping schedules are getting heavier, the ship exploitation is maximized and the time spent in port is reduced to minimum. Under the conditions, the shippers and ship operators pay greater attention to the reliability of the vessel, its systems and components. Inability to operate a ship results in various costs and loss of credibility and image on the market, according to [2].

The cylinder liner is one of the essential components of the marine prime mover and its excessive wear is one of the worst threats a ship operator may address. Excessive wear of the cylinder liner in the ring belt presents a serious problem, as shown in Figure 1, according to [2], [13].

Figure 1 Surface condition of the scuffed piston rings

Source: Class NK, *Guidance for measures to cope with degraded marine heavy fuels*, Version II, Research Institute Nippon Kaiji Kyokai, Japan 2008.

It is likely to occur when using low-sulfur fuel oil together with the cylinder lubricating oil having the *BN* 70 or higher. These oils contain excessive calcium carbonate, i.e. its content is much higher than necessary to neutralize sulfuric acid that is created during fuel combustion. Calcium carbonate settles on the piston ring lands, scraping the oil off the liner wall and causing malfunction in the lubricating process, according to [2], [13].

In order to prevent scuffing and damage to the liner and piston rings, it is possible to monitor the temperature as one of the most distinct scuffing symptoms. For instance, the Temperature Monitoring and Alarming System *T- MAS* is a dedicated system that can detect the symptoms of scuffing on the running surface of the cylinder liner in a large marine diesel engine, before the excessive wear takes place.

T-MAS detects potential problems by observing the cylinder liner temperature. Under normal conditions, there is enough lubricating oil on the liner surface. As scuffing starts to occur locally, the oil film gets thinner due to metal-to-metal contact, creating a leak for the high temperature exhaust gases. The system senses the temperature Figure 2 and sets off the alarm in the event of excessive temperature or excessive deviations in temperature, according to [2], [13].

Figure 2. Temperature sensor on the cylinder liner

Source: Class NK, *Guidance for measures to cope with degraded marine heavy fuels*, Version II, Research Institute Nippon Kaiji Kyokai, Japan 2008.

T-MAS consists of the temperature sensors, cables, switchboard, hybrid recording device and personal computer. The standard version features two sensors on each cylinder liner. The purpose of measurement is to read the temperatures at the running surface of the liner. The value observed by the thermopile is proportional to the temperature on the cylinder liner surface. In addition to careful monitoring of the liner temperature, the standard measures for preventing the excessive wear of the liner include the increased supply of cylinder lube oil, lowering the cooling water temperature in the water jacket, and temporary reduction of load on the affected cylinder by adjusting the feed fuel pump, according to [2], [13]. All these measures postpone or prevent scuffing phenomenon efficiently.

3. MEASURES TAKEN WHILE USING LOW-SULFUR FUELS

The reduction of the engine working load is the most efficient measure. It decreases the temperature and pressure inside the cylinder, as well as the penetration of the atomized fuel, thus maintaining the adequate film of lubricating oil between the cylinder liner and piston rings. Another measure is to use good fuel, i.e. fuels of low and high quality should be mixed and used. The mixture ratio is determined by the properties which are known owing to fuel analysis, or the mixture can be determined by increasing the content of low-quality fuel under careful surveillance of engine operating conditions and parameters, according to [2], [9].

In order to maintain stable operation, each engine manufacturer sets the recommended values of the concentration of *Al+Si*, *FCC* catalytic fines at the engine entry point. The recommended value of *Al+Si* for two-stroke engines ranges from 7 to 15 ppm and below. Even within the recommended range of *Al+Si*, under the influence of other factors, *FCC* fines may sometimes cause excessive wear of the cylinder liner and piston rings. Hence it is necessary to reduce *FCC* fines as much as possible, to install fuel oil filters with mesh size below 10 microns, and thoroughly clean the fuel oil, according to [1], [2], [9].

Increasing the feed rate of the cylinder oil and lowering the temperature of the cylinder liner cooling water are the measures resulting in strengthening the lubricating oil film. The temperature of the jacket cooling water *JCW* at the cylinder outlet is usually set at about 85-90°C, so that cooling is efficient at a small flow rate. In a normal engine room plan, the *JCW* outlet temperature can be made around 75°C.

In this way, the cylinder lubricating oil temperature on the cylinder liner wall surface is slightly reduced and the viscosity increases. Consequently, the strength of the lubricating oil film increases and the film becomes difficult to degrade. A decrease in engine load and an increase in lubricating oil quantity are also included in the measures for reducing heat in the lubricating oil film, which leads to enhanced strength of the lubricating oil film, according to [2], [3].

New cylinder oil feed systems have been developed and adapted in two-stroke diesel engines: Electronically Controlled Lubricating – *ECL* System, Swirl Injection Principle – *SIP*, developed by Mitsubishi Heavy Industries Ltd., Pulse Lubricating System – *PLS* Wärtsilä and Alpha Lubricator System *MAN*. These systems directly and effectively supply lubricating oil to a wide area of the cylinder liner surface.

3.1. Electronically Controlled Lubricating – *ECL* System

The Electronically Controlled Lubricating *ELC* system was developed by Mitsubishi Heavy Industries Ltd. As shown in Figure 3, according to [2], the cylinder oil accumulated in the pressurized supply line is supplied to the oil feed valves through the distributor. Its opening / closing is controlled by the solenoid valve.

Due to the accumulation of the oil at constant pressure, cylinder oil can be supplied in a steady condition without depending on the engine operating load or engine speed. The amount of the supplied oil can be freely changed by adjusting the solenoid valve and through constant feedback of the operating conditions. The oil quantity in the *ECL* system is controlled proportionally to the engine speed, break mean effective pressure and engine load.

The usual oil feed frequency is once per engine revolution, but the oil feed frequency and timing of lubrication can be changed according to the prevailing operating conditions.

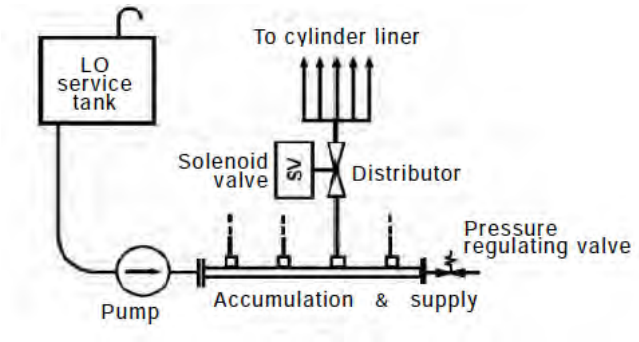

Figure 3 Conceptual sketch of *ECL* system

Source: Class NK, *Guidance for measures to cope with degraded marine heavy fuels*, Version II, Research Institute Nippon Kaiji Kyokai, Japan 2008.

3.2. Swirl Injection Principle – *SIP*

As shown in Figure 4, according to [2], the Swirl Injection Principle *SIP* lubricating system injects direct spray jets of the cylinder oil on the inside wall of the cylinder liner. It is sprayed by the scavenge air swirl. During the upward stroke of the piston, the oil is well distributed in the liner circumferential and axial directions, so that the oil film is coated evenly over a wide area of the liner surface before the piston passes. Compared to the conventional formation of the oil film by piston rings, this system of feeding the lubrication oil to the cylinder liner is more efficient.

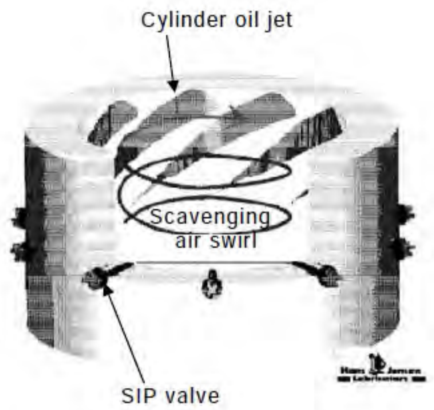

Figure 4 Overview of the *SIP* lubricating system

Source: Class NK, *Guidance for measures to cope with degraded marine heavy fuels*, Version II, Research Institute Nippon Kaiji Kyokai, Japan 2008.

The design of the oil injection valve *SIP* valve is similar to a fuel injector, according to [2]. The standard lubricator with the mechanical timing control is modified into a high pressure injection lubricator. The oil supply is proportional to the engine speed, similar to the systems having mechanical timing lubrication.

3.3. Pulse Jet Lubricating System – *PLS*

Wärtsilä Switzerland Ltd developed an electronically controlled lubrication system fitted with pulse jet nozzles, the so-called Pulse Jet Lubricating System – *PLS*. As shown in Figure 5, according to [2], the cylinder oil is injected as a pulse of multiple jets on the cylinder liner sliding surface from a number of oil injection nozzles having multiple orifices. Since the oil is injected in the form of jets and is not atomized, there is no loss of oil in the swirl of the scavenge air, and there is no external outflow of oil.

The oil injection nozzle is a simple non-return valve. In case of *RTA/RT-flex96C* engine, the oil injection nozzles with five orifices are arranged along the same circumference at eight locations. The oil amount and timing can be freely varied by electronic controls.

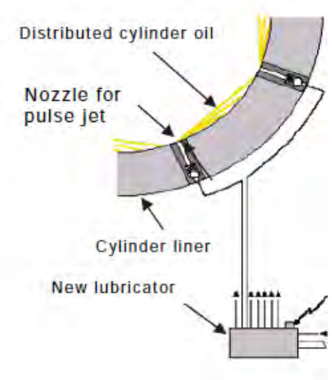

Figure 5 Pulse jet lubricating system

Source: Class NK, *Guidance for measures to cope with degraded marine heavy fuels*, Version II, Research Institute Nippon Kaiji Kyokai, Japan 2008.

3.4. Alpha Lubricator System – *MAN*

This is the electronically controlled lubricating system developed by *MAN* Diesel. This lubricating system supplies lubricating oil between the piston rings. The system feeds adequate quantity of oil to the entire cylinder liner contact surface by using the piston ring's lubricating oil retention function and coating function.

An overview of the Alpha lubricating system is shown in Figure 6, according to [2]. The controller equipped with the computer performs accurate control of the oil supply and timing, based on the crank angle signal and fuel injection pump rack signal from the rotary encoder connected to the crankshaft. Oil feed starts just before the first piston ring passes, and ends within a short time until the fourth ring passes.

Over this short interval of time, as much oil as can be delivered is fed between the piston rings. Since the oil quantity per one feed increases, oil is not supplied at each cycle; it is supplied intermittently, once in several cycles and the oil feed quantity is controlled by the feed frequency. Although not visible in Figure 6, one lubricator has 3 to 6 plungers, and it is driven by one hydraulic piston.

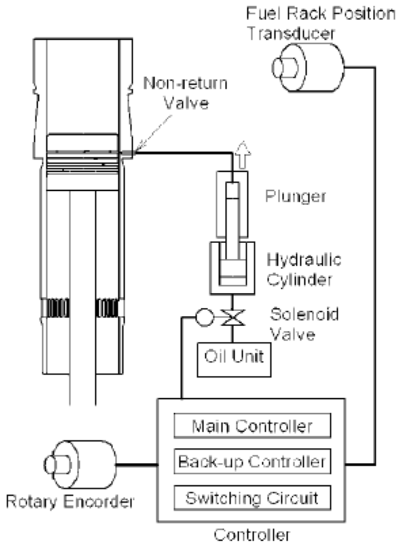

Figure 6 Schematic diagram of the Alpha lubricating system

Source: Class NK, *Guidance for measures to cope with degraded marine heavy fuels*, Version II, Research Institute Nippon Kaiji Kyokai, Japan 2008.

This oil feed valve has a non-return design. Figure 7, according to [2], shows the orifices drilled in the cylinder wall through which the lubricating oil is injected horizontally across the cylinder wall.

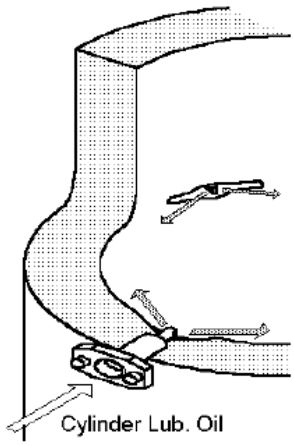

Figure 7 Alpha oil feed valve

Source: Class NK, *Guidance for measures to cope with degraded marine heavy fuels*, Version II, Research Institute Nippon Kaiji Kyokai, Japan 2008.

The above discussed systems significantly improve the reliability of the oil film and increase the margin until scuffing is reached, i.e. the occurrence of scuffing is delayed. The cylinder oil is supplied effectively in adequate quantity to the required locations, the reliability of the cylinder oil is improved significantly, and the margin until scuffing is increased as well, i.e. its occurrence is postponed. When this common phenomenon is detected, the processes resulting in scuffing may be prevented, provided that urgent measures, such as reduction of the cylinder load and/or increased supply of cylinder oil, are taken.

Finally, compared to the conventional cylinder oil feed systems, all of the above solutions require considerably smaller amount of lubricating oil. By introducing these systems, most of the problems related to the cylinder liner and piston rings due to *LSFO* effects are likely to be resolved in the near future, according to [2].

4. CONCLUSION

It is considered that the low-sulfur fuels have poor properties in terms of combustion, lubrication and running-in. Ship operators know how to avoid excessive wear of the engine components, namely by engine load reduction, increase of flow of the cylinder oil lubrication etc. However, they cannot accurately predict when the phenomenon of scuffing will occur. When it does occur, the damaged liners present a considerable cost so that great attention is given to the lubrication process and fuel quality. Over the last decade, refineries have developed a range of marine fuels through the sulfur reduction process in the products of the fluid catalytic cracking *FCC*. The properties of these fuels include a high level of density, high content of micro-carbon residue and low sulfur content, according to [2], [8], [13].

These fuels often cause excessive wear of the cylinder liner. The real causes have not been established yet but it is certain that the low-sulfur heavy oil fuels are not suitable for diesel engines, given the modern requirements that these engines have to meet.

In addition, no significant differences were observed between the commercial oils having the base number *BN* 70 and low-*BN* cylinder oils. In other words, a *BN* 40 oil does not necessarily imply that deposits will be any heavier or lighter. In the end, this is something determined by the additives. When new, some of the commercial 40 *BN* oils have high heat-resistance, but their performance drops when they are mixed with heavy fuel oil, with little difference from oil to oil. The difference in heat resistance between the low-*BN* and 70 *BN* cylinder oils results from additives, not the base number, according to [2], [13].

With regard to the anti-scuffing properties, 70 *BN* cylinder oils perform better than the low-*BN* oils. Again, the rate of neutralizing sulfur acids is to the greatest extent affected by additive composition, not the base number. High-performance 40 *BN* oils could substitute 70 *BN* oils, provided that sulfuric acid neutralization does not result in decreased alkalinity. The 40 *BN* oils outperform all commercial products and could serve as models for future cylinder oils, according to [2], [8], [13].

Therefore, for the time being, the very properties of the cylinder lubricating oils do not present an issue in terms of scuffing prevention. However, due to the trend of developing larger marine diesel prime movers, it will be necessary, sooner or later, to pay more attention to the scuffing resistance as the essential property of cylinder oils.

The analysis of the possible causes of the experienced problems reveals that, today, these issues are largely examined from the technological aspects and from the standpoint of the propulsion requirements during the fuel switch-over procedures on board ships. According to [3], [10], errors made by ship operators also have to be thoroughly studied and taken into account; the causes of scuffing and associated problems should also be observed from the organizational viewpoint, both at sea and within the company.

REFERENCES

[1] ABS, *Fuel Switching Advisory Notice*, American Bureau Survey, Houston 2010.

[2] Class NK, *Guidance for measures to cope with degraded marine heavy fuels*, Version II, Research Institute Nippon Kaiji Kyokai, Japan 2008.

[3] Djini R., Dvornik S., Dvornik J.: *Analysis of the effects of low-sulphur fuel oil on marine diesel engines operation*, International Maritime Science Conference, Book of Proceedings, 6th IMSC, April 28th-29th, Solin, Croatia, pp. 11-18. 2014. ISSN 1847-1498.

[4] Liddy J. and Lim K. C.: *Cylinder oil - positioning for the future*, Motorship Amsterdam Congress 2000.

[5] MAN Diesel & Turbo, *Operation on Low–Sulfur Fuels*, MAN B&W Two–stroke Engines, Copenhagen 2010.

[6] Radan I.: Fuels and their application on ship, final work, Faculty of Maritime Studies, Split, Croatia, 2019.

[7] *Report on application of low sulfur fuel to marine diesel engine*, Fuel and Lubricant Committee, the Japan Institution of Marine Engineering, Research Report No. 369, 2005.

[8] Sasaki T., Moriwaki T., Noge T., Shirahama S., Arimoto N.: *The differences of commercial cylinder oils perfomances for marine low speed diesel engine between 70BN and 40BN for low sulfur content marine fuel oil,* International Council on Combustion engines, 2005, CIMAC, paper No. 161.

[9] Tireli E.: *Goriva i njihova primjena na brodu*, Faculty of Maritime Studies, University of Rijeka, 2005.

[10] Zekić A., Radonja R., Berenčić D.: *Promjena goriva na brodu u kontekstu sigurnosti plovidbe*, in: Naše more / Our Sea Journal 59 (5-6), 2012.

[11] Wakatsuki Y.: *Fears of Low Sulfur Fuel Oil*, Mitsubishi Heavy Industries, Ltd., Journal of the Japan Institution of Marine Engineering, 2006, Vol. 41, No. 1.

[12] Wakatsuki Y., Watanabe K., Yamamoto T. and Takaishi T.: *Relation between Recent Low Grade Fuel and Reliability of Marine Diezel Engines*, ISME Tokyo 23-27 Oct. 2000, Paper No. TS – 66.

[13] Wakatsuki Y., Watanabe K., Yamamoto T. and Takaishi T.: *T-MAS, the detector of scuffing before excessive wear*, Proceedings of the 7th International Symposium on Marine Engineering Tokyo, 2005, October 24th to 28th.

OPPORTUNITIES FOR ALL-ELECTRIC SHIPS IN SMART ENERGY SYSTEMS

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Summary

Greenhouse gas emissions have been a major concern in recent years where maritime sector has a significant contribution as well as in energy usage. Since maritime technology has begun to replace mechanical propulsion by electric propulsion, it gives the opportunity to replace conventional fuels with alternative ones such as electric batteries and renewable energy source. Today's researches and practice have shown that the future energy systems are developing as a smart energy systems using energy produce by the renewable energy source replacing conventional ones, aiming to reduce emissions to minimum. Electric ships can also find their place in smart energy systems, through integration of intermittent renewable energy sources, and play an important role in smart grid concept integrating ships and ports, reducing its negative impact on the environment. This work presents opportunities for the electric ships in future energy system seeking replacement of conventional fuels with alternative ones in order to reduce global pollution. Comparison of the electric ships with the conventional ones in the field of operational, financial and social aspects is also provided within this work. On the example of the Dubrovnik region, aiming to achieve 100% electricity production from the renewables till 2050, is show that the all-electric ships could be good option for the integration of renewables in smart energy systems through shore-side power concept.

Keywords: all-electric ships, electric batteries, greenhouse gas emissions, renewable energy sources, smart energy systems

1. INTRODUCTION

The whole world in different sectors is aiming to reduce greenhouse gas emissions trying to reach their minimum. Transport sector has a share of 20% of total primary energy consumption and 24% of total global emissions [1]. The maritime sector has a significant role in the transportation sector carrying around 90% of the global trade in volume and more than 70% in value, which makes it very important for the global economy and international shipping [2]. Many improvements have been done so far in maritime sector with a higher energy efficiency of ship engines, using new type of fuels such as liquefied natural gas and improving ship energy systems, but there is still more that can be done. It has been estimated that a maritime sector is responsible for the production of 3% of total global greenhouse gas (GHG) emissions [3]. The emissions of carbon dioxide (CO_2) from ships in 2012 were of 938 million tons, which makes shipping responsible for 3.1% of total global CO_2 emissions in 2012 [4]. Shipping accounted for nearly 2.8% of the annual anthropogenic GHG emissions on a CO_2 - equivalent basis in the period from 2007 to 2012, which shows that the maritime activities are rapidly growing due to the increase in maritime transport [5]. The projections for 2030 are showing that the shipping trade volume will reach around 20 billion tons which will be two times greater than the baseline and will have a significant environmental impact [2]. Shipping makes an important part of total transport sector and it energy usage is still based on fossil fuels, which results in considerable air pollution, although it accounts fewer number of operational vessels in the total global fleet. Standards for emission of air pollutants are less strict for marine fuel than on other transportation modes. It is projected that the overall shipping CO_2 emissions will rise within 50-300% up to 2050 in the absence of regulations [4], [6]. All of the data carried out are showing that the maritime sector will play an important role in achieving the global emission reduction targets in the near future.

For these reasons, the International Maritime Organization (IMO) created a regulatory framework in order to enhance energy efficiency for the maritime sector. It defined the Energy Efficient plan in 2010 [6] and the Energy Efficiency Design Index for new ships and the Ship Energy Efficiency Management Plan for all ships was enacted in 2013 to control CO_2 emissions from ships [1]. In April 2018 IMO held strategy meeting resulting in agreement to reduce the total amount of annual GHG emissions by 50% till 2050 compared to 2008 [4], [5]. It has been estimated that the usage of 0.5% low-sulphur fuel within coastal areas could prevent 33,500 premature deaths annually, which is the reason why this reduction is consistent with an upcoming global restriction imposed by the IMO from 2020 [7]. The IMO is expected to include more areas in stricter emission control areas for nitrogen oxides (NO_X) and sulphur oxide (SO_X) emissions of global anthropogenic emissions in the transportation sectors [1]. In the period 2007-2012, maritime emissions, like the Mediterranean Sea and the global waters [2]. Such areas with a higher emission control are Sulphur Emission Control Areas (SECA) and Emission Control Areas (ECA). The declaration of ECA provided stronger regional restrictions requiring the use of 0.1% low-sulphur fuel,, which has shown to reduce mortality by half when used only at berth [7]. Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL) aims at a progressive reduction of emissions of GHG, NO_X and SO_X. According to the regulation 13, acceptable NO_X emission limits depend on the engine capacity and year the ship was built. In accordance with Regulation 14, released SO_X and particulate matter (PM2.5) emissions are controlled and restricted by a limit on the sulphur content of marine fuels. The sulphur content may not exceed 0.5% on or after January 1, 2020 [1], [5], [8]. Despite this regulatory framework, maritime sector still has a major impact on global CO_2 emissions. Although certain geographical areas in Europe, North America and China have been designated as ECA for air pollutants, shipping still remains the least regulated transport sector according to the air pollution. The best marine sulphur standard provided by the declaration of ECA, requiring the use of 0.1% low-sulphur fuel, remains 100 times worse than road diesel/petrol which is 0.001%, for the past 15 years. Figure 1 shows the comparison of European sulphur standard in marine and road fuels [8]. Recent studies have shown that increasingly large proportion of NO_X and SO_X depositions on land in coastal regions and port cities come from ships [8]. It has been projected that although shipping now accounts for only 2.2% of the global CO2 emissions, it might reach 17% by 2050 if no measures are taken. Around 90% of CO_2 emission reduction is required in order to keep the temperature increase below 2°C. Along these lines, it has been discussed to tax the carbon emissions, similarly to the land-based power plants [2].

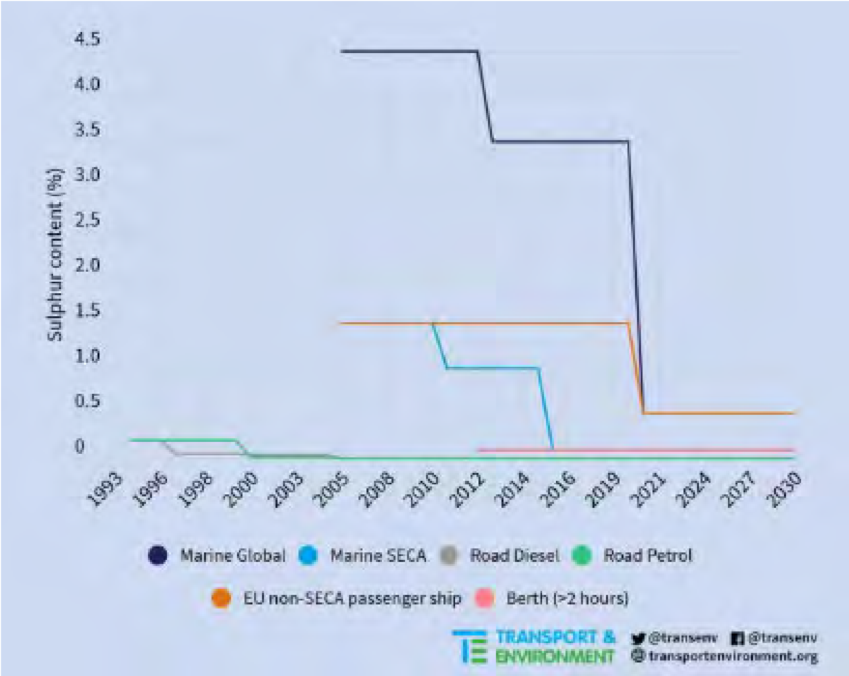

Figure 1 EU Sulphur standards for marine and road fuels [8].

Source: C. C. A. Faig Abbasov, Thomas Earl, Nicolas Jeanne, Bill Hemmings, Lucy Gilliam, "One Corporation to Pollute Them All," Transp. Environ., no. June, 2019.

Technical and operational solutions for improving energy efficiency are gaining god results since the energy efficiency per ton kilometre has significantly increased by 5.8% in the period 2010–2014, but the reduction of the total GHG emissions is not improving due to the steady growth of the shipping sector. This is why it is more likely that in the near future a tax on CO_2 shipping emissions will be adopted [4]. Some countries have introduced additional regulations, for example, Norway introduced a NO_X tax in 2007 that applies to various sectors, including domestic shipping and fishing [5]. The study [2] explored the optimal cruise ship energy systems configurations to comply with the future carbon pricing policy scenarios and estimated that the baseline cruise ship energy system configuration does not present the optimal solutions in any of the examined carbon pricing scenarios. The results indicated that a new technologies need to be introduced in the future cruise ship configurations like natural gas, waste heat recovery technologies and fuel cells. The greatest reduction of the CO_2 emissions is gained combining fuel cells with carbon capture technology. Ship-based carbon capture technology on diesel or (liquefied natural gas) LNG-fuelled vessels is presented in study [4] to be a transition solution towards GHG emission reduction. Study [3] provided results of energy efficiency increase of cruise ships using waste heat recovery technology and LNG as a power source.

The global warming is an international issue, which requires a decrease of fuel consumption and greenhouse gas emission in all types of ships. Electric propulsion in boats, ships and vessels is a key issue to reach a better and more sustainable maritime transportation. The propulsion system efficiency needs to be improved in order to achieve this goal. Electric propulsion could optimize the operation of on-board generators and facilitate the use of (renewable energy source) RES, fuel cells or batteries in order to generate clean electric power. Electric propulsion in marine applications is dating back over 100 years and it became increasingly popular after the development of high power variable speed drives in the 1970's–1980's [9]. In order to improve propulsion system efficiency, study [9] analysed optimization-based energy management strategy using model predictive control. Study concluded that fuel cell systems seem to be a very attractive solution for on-board ship power generation and they can be fully integrated into an all-electric ship (AES) concept. Paper [10] studied the possibilities of using fuel cells in ships. Other studies [11], [5] and [6] also analysed possibilities of using fuel cells and batteries in hybrid electric propulsion systems. Study [6] dealt with the use of hybrid electric propulsion in excursion ships and the main result was the reduction of the local CO_2 emission by 1.39 kg in the casting-off and docking manoeuvres. The paper [11] studied new hybrid energy storage system for waterbus application in Venice. Fuel cell applications are still affected by safety issues, related to the on-board hydrogen storage, which involve higher management costs and design limitations [11], but on the other hand they reduce vibration and noise, which can benefit the crew, passengers, harbour communities and marine life [5]. Recent battery technologies based on lithium compounds justify the growing interest towards the use in AES concept due to the reduction of costs and high energy density performance. High amount of energy can be stored on-board since ships are generally less sensitive to weight constraints, when compared to a road transport. There are different constrains that need to be taken into a consideration when designing on-board battery pack. These are the number of battery elements as they depend on the amount of energy required to complete shop mission on an assigned route; at the end of the working period the state of charge should not be lower than a minimum value as the depth of discharge affects the expected life of the battery; the number of charging/discharging cycles and high peak current values effect on the expected battery lifetime. The use of hybrid energy storage systems and super capacitors can improve energy storage performance in terms of lifetime and efficiency. Peak power values required by the electric drive can be supplied by super capacitors, using proper management of on board power electronics devices [11].

The global concern in reducing GHG emissions and decreasing fuel consumption led to new methods of using RES on ships and concept of shore-side power (SSP) to meet the electrical energy demand of ships. SSP is the concept of providing power from the national electricity grid to the ship while its main engine and auxiliary engines are shut down at the ports of maritime nations. SSP has been installed in nearly 20 ports worldwide since 2000 and is planned for seven ports more [1]. This work will analyse the opportunities of AES concept in the system of SSP in ports which are arranged as smart energy systems using power produced from RES. Dubrovnik (Croatia) is selected as a port and a city that has the opportunity to develop as a smart energy system as shown in study [12] and is busy port according to a high number of cruise ships arrivals. The paper will be based on cruise ships since Dubrovnik is their frequent destination. Cruise ships are also the ones with a higher level of emissions in ports and are shown to be the best in the concept of AES, since they have the most dynamic operational profiles and spend a large proportion of their operational time with lower loads, where their energy efficiency is significantly reduced [5].

2. EMISSIONS FROM SHIPS

Conventional ships still base their energy sources on fossil fuels causing negative impact on environment, human health and climate. The majority of GHG emissions from ship is contained of CO_2. Other GHGs formed in the combustion are methane and nitrous oxides. CO_2 contributes approximately 98%, and CH_4 and N_2O together 1%-2% from ships in port emission inventories, when comparing the global warming potential of CO_2, CH_4, and N_2O from combustion in marine engines. Emissions from LNG engines have shown that the methane is responsible for approximately 25% of the global warming potential of the emissions. Black carbon (BC), a component in soot, is another climate forcer. Rest of the emissions from ships are contained of NO_X, SO_X and PM2.5 [13]. The maritime sector is responsible for about 4.5% of total energy use and for 3% of CO_2, 11% of NO_X, and 4% of SO_X emissions of global anthropogenic emissions in the transportation sectors [1]. In the period 2007-2012, maritime sector produced approximately 15% of NO_x and 13% of SO_X emissions from anthropogenic sources [5]. GHG emissions cause climate change and are affecting human health causing premature mortality and environmental impacts such as acidification and eutrophication of waterways. NO_X and SO_X can cause photochemical smog, acid rain and consequent health problems and along with fine PM2.5 cause premature death, including from lung cancer and cardiovascular disease and morbidity, e.g., childhood asthma. It has been estimated that ship-related PM2.5 are responsible for 60,000 cardiopulmonary and lung cancer deaths worldwide in 2002 [5], [8], [7].

Approximately 70% of global ship exhaust emissions occur within 400 km of the coast [5], [7]. Different studies in various countries estimated the contribution from ships to ambient PM2.5 near ports to range from 1% to 17% [7]. Most ports are located in populated areas where emissions from transport sector have high impact on human health, environment and climate. Ships are the single largest source of port-related pollution, causing emissions approximately 10 times greater than those from the ports' own operations. The estimation from 2002 shows that only 6% of the fuel consumption of ships occurs in port areas, but there is also difference between ship type. Most merchant ships spend most of their time at open sea, but on the other hand, cruise ships spend lots of time in ports. Although the majority of ship emission occur at sea and not in ports, ports suffer from a higher risk due to high emission exposure since they are often placed in cities and people are exposed to the emitted pollutants to a higher extent than emissions at sea. This is why it is important to consider emissions from ships, specifically in port areas, and find suitable ways to reduce them. Appropriate measures to apply depending on what air emissions are targeted, if the ship is on route or at berth, and ship type. Different operations and speeds have different power requirements which effect on the amount of installed engine power usage. Fuel type is an important factor that has a great influence on emission of SO_2 and particles. The traditional marine fuels are different grades of heavy fuel oil (HFO) and marine gasoil (MGO). The dominant marine fuel in international shipping is HFO with sulphur content up to 3.5%. Fuel alternatives include MGO, so-called low sulphur fuel oil (LSFO) and LNG. Engine type is another factor. There are two types of engine, slow-speed two-stroke engines and medium- and high-speed engines of four-stroke type. Two-stroke engines have higher combustion temperatures which increase NO_X formation and emissions of NO_X, resulting in higher emissions. Four-stroke engines are common as main engines on many ships, as well as cruise ships, and are more compact design. Two-stroke engines are more fuel efficient. When ship is on the sea it uses its main engine, but when on berth auxiliary engines are run to provide the ship with electricity. Emissions from main and auxiliary engine account for between 5%-30% and 49%-76% and boilers account for 15%-40% of GHG emissions in ports [13]. Ship emissions in ports are based on the auxiliary engines and boilers since they run ship when on berth. Study [7] examined methods for calculating the actual operating power of auxiliary engines and auxiliary boilers. Different ship types and shipping services have different requirements so it is hard to gain unique solution that can be applied to individual ships and ports.

2.1 Cruise ships

In the tourism sector, the cruise ship industry presents the fastest growing segment in recent years. It has been reported that around $25 billion worth of cruise ships have been ordered from 2016 to 2022. In 2014, the revenues from cruise ship operations globally accounted for $37 billion. Cruise ships fuel consumption as a share of 10% of the overall annual consumption of ships with more than 30 million tons of fuel oil. It is estimated that cruise ships have more CO_2 emissions per passenger-kilometre from economy class aviation. Cruise ships emitted 35 million tons of CO_2 emissions corresponding to 4.4% of the emitted CO_2 from the global ship fleet for the year 2012. Cruise ships, with configuration for the cruise ship power plant of the 'fully electric' type, constitute one of the highly energy intensive ship types with complex energy systems, due to their high energy demand for the passengers' accommodation and services. Total cruise ship power requirements are consisting of the power demand for the propulsion, electric power and auxiliary systems, power for operating the heating, ventilation and air conditioning systems, as well as for generating the required amount of fresh water [2]. Significant percentage of the total energy is dedicated to the passengers' needs as shown in Figure 2.

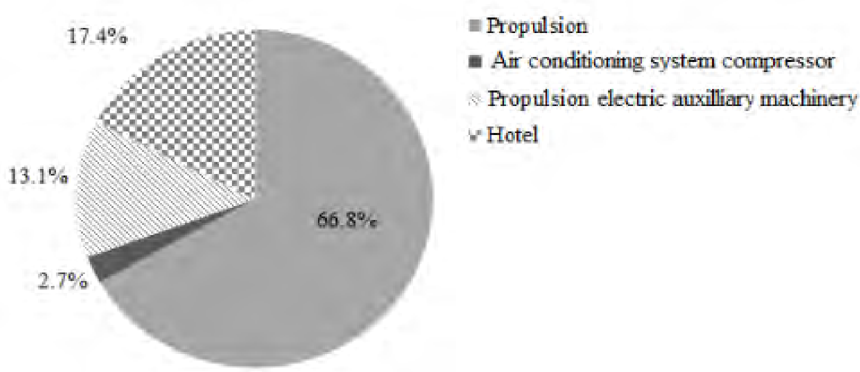

Figure 2 Cruise ship energy distribution from on-board measurements [2].

Source: N. L. Trivyza, A. Rentizelas, and G. Theotokatos, "Impact of carbon pricing on the cruise ship energy systems optimal configuration," Energy, pp. 952–966, 2019.

Cruise ships spend more than 30% of their operating time in ports resulting in significant amount of emissions in ports causing serious human health problems. The most popular area for the cruise ships operation is the Caribbean and lately the Mediterranean Sea, where operations considerably increase especially during the summer seasons. Together those regions account for 70% of the global cruise industry. The cruise ships greatest market is on seas that belong to the ECA or areas that are possible to be characterised as ECAs in the future [2].

2.2 Dubrovnik port

The study [8] done a research of pollution emissions from 203 cruise ships in European costal region in 2017 and compared it to the emissions form passenger cars (light duty vehicles – LDV). The report found that in 2017, 203 cruise ships in Europe emitted about 62 kt of SO_X, 155 kt of NO_X, 10 kt of PM and more than 10 Mt of CO_2 and most of the emissions took place in Mediterranean Sea.

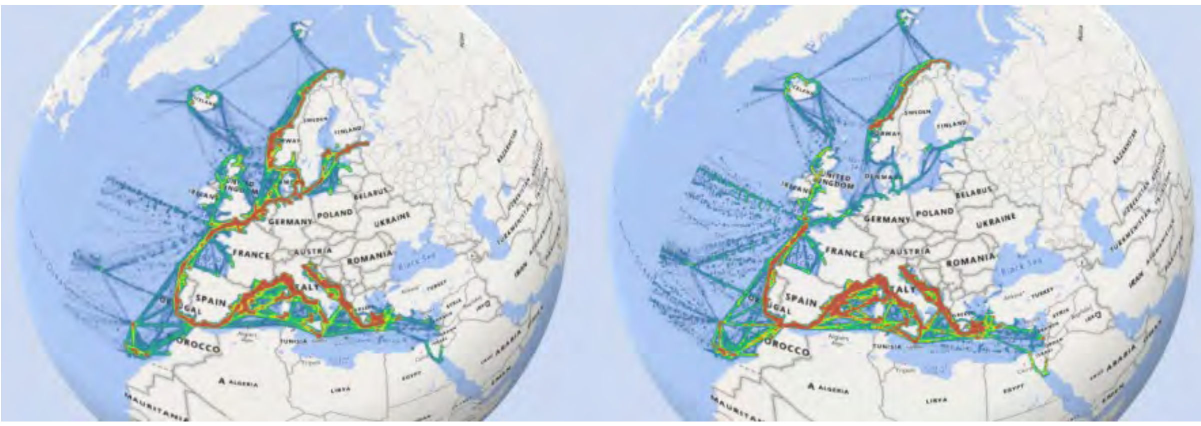

Figure 3 Heat map of NO_X and SO_X emissions from cruise ships in 2017 [8].

Source: C. C. A. Faig Abbasov, Thomas Earl, Nicolas Jeanne, Bill Hemmings, Lucy Gilliam, "One Corporation to Pollute Them All," Transp. Environ., no. June, 2019.

Figure 3 shows the heat map of NO_X and SO_X emissions from cruise ships in 2017. It can be seen that the Croatian coast is well exposed to those emissions. Croatia has the highest ratio of ship to LDV SO_X emissions among the EU countries, with 78 cruise ships outdoing the national passenger vehicles by a factor of 189. Croatia cruise ships emitted more NO_X than the entire domestic passenger car fleet in a year. Table 1 provides the data of SO_X emissions from cruise ships in Dubrovnik in comparison to LDVs [8]. Gained results show that the cruise ships emitted almost 20 times more kilograms of SO_X, 140% more NO_X and 20% more PM2.5 than the entire Dubrovnik LDV fleet in 2017.

Table 1 Emissions of SO_X, NO_X and PM2.5 from cruise ships and LDVs in Dubrovnik port in 2017 [8].

Number of cruise ships	SO_X from cruise ships (kg)	SO_X from registered LDVs (kg)	Ratio of SO_X from cruise ships and LDVs
40	6,344	331	19.2
Port call time (hours)	NO_X from cruise ships (kg)	NO_X from registered LDVs (kg)	Cruise ship NO_X vs. LDVs (%)
2,791	140,259	100,174	140.0%
Number of registered LDVs	PM from cruise ships (kg)	PM2.5 from registered LDVs (kg)	Cruise ship PM2.5 vs. LDVs (%)
27,173	2,523	11,561	20,1%

Source: C. C. A. Faig Abbasov, Thomas Earl, Nicolas Jeanne, Bill Hemmings, Lucy Gilliam, "One Corporation to Pollute Them All," Transp. Environ., no. June, 2019.

Provided data in study [8] show that the ship sourced air pollution is a huge problem in Europe and it can be expected that the similar level of pollution will be elsewhere to. Gained results indicate that the new methods need to be considered in order to decrease emissions and air pollution.

The study [14] analysed and compared emissions from cruise ships in ports of Dubrovnik and Kotor (Montenegro) in the period 2012-2014. It showed that the period from May to October where the busiest months during 2012-2014 according to port calls and anchored calls. It was estimated that the damage costs of NO_X, SO_2 and urban PM for Croatia were equal to 15,149, 12,317 and 208,779 euros per emitted ton, respectively. The air pollution damage has shown to be from 8.5 to around 10 euro per passenger for the port of Dubrovnik. The ships calling at the port of Dubrovnik have produced higher emission levels than the ships calling at Kotor. This is partly due to the influence of the higher number of port calls, although other parameters such as ship size, port time and ship activity can also affect the level of produced emissions. The contribution of the manoeuvring phase for Dubrovnik port is found to be significant (around 30%) because of the navigational complexity. The port of Dubrovnik imposes upon ship operators a complex manoeuvring procedure which leads to increased emissions and even higher air pollution damages due to its urban characteristics. The results indicated that the control of air pollution from ships and for a given port calling demand, the available port infrastructure in terms of its complexity and adequacy constitutes a decisive factor.

3. ALL-ELECTRIC SHIP CONCEPT

The AES has been used in icebreakers and cruise ships for many years and it is not a new concept. Electric motors and generators have points of failure during its work. Difference between electrical and mechanical drive ship is that in mechanical drive ships, if one generator or motor failed there is always a back-up unit that would meet the operational requirements, but in the all-electric ship, if one of the main motors or generators fails, there is a very significant loss in operational capability [15]. The ship electric propulsion directly drives the propellers. The propulsion device generally is consisted of propellers, motors, generators, prime mover and the control conditioning and other components. Electric propulsion has low noise, good mobility, flexibility shipping space since the propulsion motor and generator are connected by a power cable and other advantages. Using electric propulsion can avoid the prime mover's wide range speed regulation and improve its efficiency [16]. Electric propulsion requires 10-15% less fuel than a mechanical propulsion system does. [17]. One of the classic problems is propulsion-load fluctuations, which are caused by the propeller rotation and encounter waves and can significantly affect both mechanical and electrical systems, but they are more pronounced for electrical propulsion systems [18]. Integrated power system, enabling AES technology, provides the electrical power for both ship service and electric propulsion loads by integrating power generation, distribution, storage, and conversion. It offers considerable benefits to modern ships, although technical challenges exist. For example, the propulsion load fluctuations experienced by the propeller have very different implication in comparison to the traditional mechanical drive systems because of the interconnectivity brought in by the integrated power system, as these fluctuations can affect the electrical shipboard network through the electric motors and their drives [19]. When used in the concept of SSP, electric ships represent the greatest load connected to the power grid and its behaviour will impact the entire distribution system. Frequency converters generate harmonic currents, which can influence the grid, causing voltage distortion. Interaction of voltage distortion with other equipment connected to the grid can cause unwanted disturbance [20]. This problem calls for new solutions that could effectively address the load fluctuations to assure reliability and integrity of the overall electrical network. Selection of the right equipment, the right electronic communications, the right sensors, and the right condition indicators that will allow the computer to provide prognostic health management, thus alerting the operator to a developing problem, are of a huge importance to ensure successful operation of the electric system [15].

Hybrid electric propulsion systems (HEPSs) and hybrid energy storage systems (HESSs) are considered as one potential solution in order to address the impact of propulsion-load fluctuations and enabling diesel engines to work within the high efficiency region under various working conditions with the aid of electric machines. HESS has already been used for considerable applications, such as hybrid electric vehicle, micro-grid and all-electric ship, providing complementary characteristics and achieve desired performance. In AES concept, HESS serves as a buffer to absorb power when the propulsion motor is under-loaded and supply power when it is overloaded, thereby isolating the electric shipboard network from propulsion load fluctuations. On the other hand, plug-in HEPSs can reduce further fuel consumption and extend the zero-emission range when operated in pure electric mode through the use of SSP that is charged into large capacity batteries. The effectiveness of the proposal HESS and HEPS solution highly depends on the system energy management strategy (EMS). An effective EMS should provide improved fuel efficiency, enhanced response speed, superior reliability, and reduced mechanical wear and tear in order to achieve robust and efficient operation and to meet various dynamic operational requirements. EMS for HEPS is used to coordinate the operation of the diesel engine, motor, and generator, also to coordinate the usage of electricity from the battery and the shore power plant, aiming to fulfil the power required by the propellers, hotel load and service load of the plug-in HEPS [19], [21]. Previous studies have analysed the effectiveness of those systems using different EMS [9], [11], [18], [19], [21], [22], [23]. Paper [9] explored a real-time model predictive control based energy management strategy for load fluctuation mitigation in all-electric ships. A battery combined with ultra-capacitor hybrid energy storage system (HESS) is used as a buffer to compensate load fluctuations from the shipboard network. The results showed that the bus voltage variation and hybrid energy storage losses can be reduced by up to 38% and 65%, respectively. Study [18] analysed model predictive control (MPC) and multi-objective optimization problem (MOP) as EMS. The results showed the effectiveness of the proposed MPC in terms of power-fluctuation compensation, HESS energy saving and reduction of the battery usage and high-current operation. Paper [21] presented bi-objective optimization design to achieve a compromise regarding fuel consumption and GHG emissions. The results showed 42.26% lower fuel consumption and 0.91% lower GHG emissions in comparison to the conventional propulsion system. Simulation results from study [23] showed that the proposed method can ensure not only minimum operation cost but also reduced GHG emissions.

Battery energy storage system is another option for full electric ships providing power from the distribution grid thought SSP or directly from RES. BESS is usually interfaced to the power distribution grid with its own power converter, but it can also be connected directly to the DC-link of the electric propulsion system, eliminating the need for a DC/DC converter, but increasing the size of the frequency converter and the propulsion inverter that has to control the voltage of the DC-link to control the state-of-charge (SOC) of the BESS. The on-board DC grid is being adopted for various applications in recent time. Its advantages versus traditional AC systems regarding dynamic positioning operation of offshore support vessels include improved efficiency, optimization of operation and fast ramping connected with the integration of energy storage. The implementation of DC grid may reduce the electrical equipment footprint and weight of up to 30%, as the bulky AC switchgears and transformers are removed in the shipboard DC grids, and the fuel consumption and emissions by 20%, as the DC power system enables the prime movers to operate at their optimal speeds. DC system eliminates the need for multiple stages of conversion and transformation that the AC system usually requires when integrating a device with DC output, such as an energy storage device [24], [25]. Studies, [16], [24], [25], [26], [27], [28], [29] analysed DC systems. Results from study [25] provided an average fuel saving of around 15% compared to the conventional DC systems. The study also showed that the shipboard DC system with energy storage could provide a fuel saving of around 7% compared to the DC system without energy storage.

3.1 Electric batteries

The best choice for AES BESS today is shown to be the Li-ion battery, whose performance keeps improving continuously, while its cost is reducing quickly. The cost per kWh for electric vehicles (EV) batteries dropped by 35% during 2015, since battery manufacturers are ramping up production to meet increased demand from electric vehicles and stationary energy storage. Improvements in energy density is also an important factor, which increased interest in batteries for EVs in combination with environmental and energy issues.

Li-ion batteries based on lithium nickel manganese cobalt oxide (NMC), lithium nickel cobalt aluminium oxide (NCA) or Li-phosphate (LFP) cathodes and carbon or Li-titanate (LTO) anodes may be chosen depending on the system requirements for a BESS in a marine application, which includes power profile, design lifetime, footprint and safety, etc. Different battery systems have their respective strengths and weaknesses in terms of cost, charge and discharge rate capabilities, calendric and cyclic lifetimes and safety. This is the reason why most BESS have to be designed with a sufficient initial over-sizing in order to cope with the fade in energy capacity and/or power capability over its lifetime. A marine BESS is typically comprised by one or more parallel strings, in order to meet energy capacity and power capability requirements, with a nominal voltage in the range of 700 and 1000 V.

4. SHORE SIDE POWER

The opportunity for ships to integrate into the national electricity grids can be obtained through the SSP application. The environmental and economic effect of using RES on shipboard can be successfully evaluated through the smart grid infrastructure used with an SSP connection thanks to energy management, two-way communication and two-way power flow features. SSP connection considering the smart grid concept operates in the way that energy management units collect the information about power capacity from electrical energy sources, voltage and frequency characteristics, price, and emission data from shipside and port side, as it is described in Figure 4 [1].

EMS presents the key element of the successful operation of such systems. EMS works based on the determined algorithm in order to use energy according to the priority in the way to meet the both economic and environmental priorities. RES should represent primary energy source, since they are environmentally friendly, aiming to reduce emissions. They can be used as an installed power source on-board or through the national electricity grid using SSP concept. ESS on the ship is used to store and restore energy. If the capacity of RES is insufficient, ESS will be discharged and supply ship with energy, otherwise they will be charged. Auxiliary engines are used if none of the previous options is available. Whichever energy source is cheaper or cleaner according to the criteria is preferred as the priority energy source. This concept provides the possibility for ships, using RES and ESS, to supply electrical energy to the national grid. In this way ships can reduce its energy consumption and at the same time support the port side as the micro grid [1].

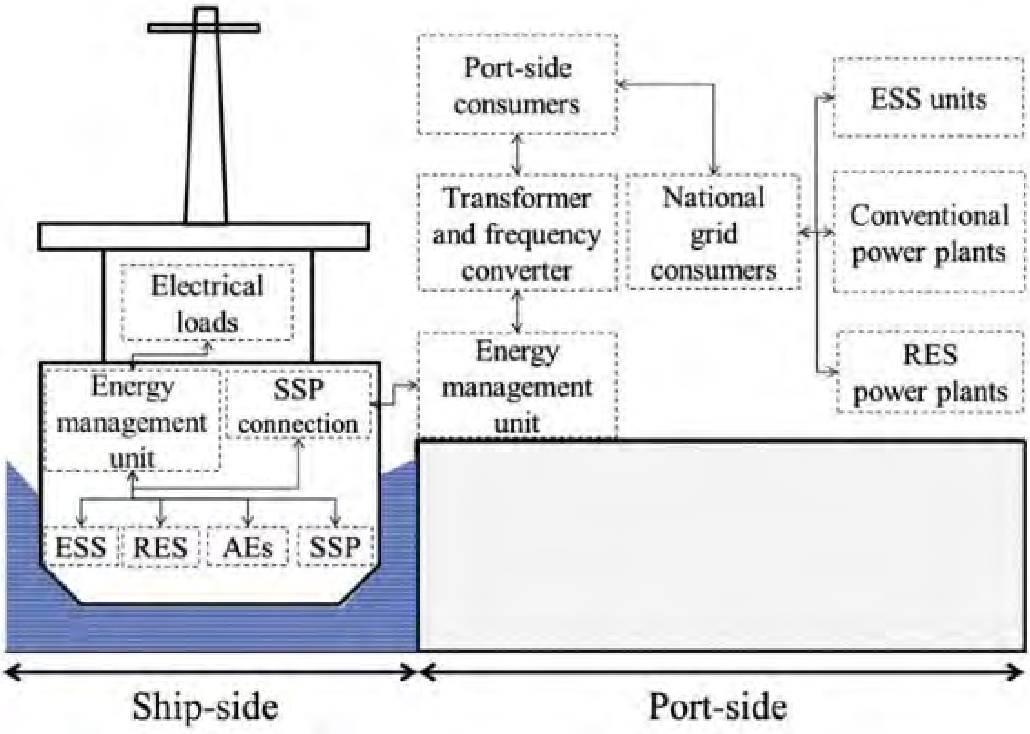

Figure 4 Shore-side power (SSP) connection using smart grid infrastructure. AEs, auxiliary engines; ESS, energy storage system; RES, renewable energy system [1].

Source: K. Yiğit and B. Acarkan, "The Importance of Ships in the Next-Generation Electric Power Systems," in Exergetic, Energetic and Environmental Dimensions, 2017, pp. 167–178.

Concept of SSP is well explained and analysed in study [1] comparing two case studies. In the case study, the container ship and the port of Rotterdam, which is Europe's largest seaport, are taken into account. In Case 1 ship is only using auxiliary engines without EMS, RES, ESS and SSP. In Case 2 ship has RES and ESS and uses EMS and SSP connected to the smart grid. The results of the algorithm show that Case 2 is more economical and environmental than Case 1. The total cost of electrical energy can be decreased by 77% and CO2 emission can be reduced by 75% by using both RES and the EMS algorithm on the ship.

SSP enables ships at berth to connect to the local electricity grid and power their on-board equipment which can affect to the reduction of the local air pollution generated by docked vessels in ports. The SSP application is available in some ports, but not frequently enough due to some barriers [1]. One of the problems is the lack of grid capacity, due to a high energy demand of ships. Grid emission factors can be more than the ship's auxiliary engines if electricity provided by grid is product by conventional power plants and not using RES. GHG emissions from the electricity production by coal is higher than that by fossil fuels and other renewable sources because coal is more carbon-intensive. Thus, overall emissions from ships could increase using SSP. Therefore, it is necessary to consider not only fuel consumption but also GHG emissions [21]. Initial investment costs may also be high for ship owners and port authorities in many maritime nations. There is also a market distortion because of taxation. SSP is taxed under the 2003 EU Energy Tax Directive, while fossil marine fuels are tax exempt. Such an uneven playing field creates a disincentive for ship owners to use SSP in ports wherever these technologies are available. Limited connections available in ports affect owners of the vessels not to invest in ships to make them SSP-compatible, while at the same time ports do not invest in SSP connections because few ships can use them [8].

These barriers can be overcome by integrating smart grids in the future. The capacity of the electricity grid will be used more effectively with the ability for advanced sensing technologies if maritime nations use more RES and ESS systems in their ports or regions. This would lead to the reduction of grid emissions and the initial investment costs due to the lower maintenance and operating costs. Maritime sector representatives should consider next-generation electric power system applications and projects to provide energy efficiency. Governments should develop financial support in order to encourage smart grid applications. The use of RES and their sustainability on shipboard should be more examined. Two-way electrical energy and information flows between ship and grid should be considered by using energy management systems [1].

4.1 Smart energy systems

The smart grid infrastructure presents an effective solution to provide energy efficiency and optimum electrical energy use on shipboard for the maritime sector. It refers to the intelligent electricity grid, which puts advanced sensing technology, control methods, real-time monitoring, energy management and two-way power and information flows into the traditional electricity grid, managing electricity from generation to consumption. Smart grid integrates different power sources such as traditional power plants, micro grids, EV, RES, and ESS using energy management algorithms as a key element to ensure energy efficiency. Concept of smart grid with its components is presented in [1].

Figure 5 Smart grid components. ESS, energy storage system; EV, electrical vehicle; MG, micro grid; PV, photo-voltaic; SSP, shore-side power; WT, wind turbine [1].

Source: K. Yiğit and B. Acarkan, "The Importance of Ships in the Next-Generation Electric Power Systems," in Exergetic, Energetic and Environmental Dimensions, 2017, pp. 167–178.

This work will consider smart energy system as an effective solution to reduce overall emissions using energy produced by RES and discus the opportunities for AES to integrate in such systems. Within in this work we discussed the opportunities for the integration of cruise ships into the 100% renewable power system of the Dubrovnik region.

4.2 Opportunities for AES in smart energy system of the Dubrovnik region

Dubrovnik is known as a popular cruise destination counting a large number of cruise ship arrivals causing huge increase in total emissions. Cruise ships have much higher emission than the entire vehicle fleet of Dubrovnik region as it was presented in Table 1. Since Dubrovnik is urban populated area, air pollution significantly affects human health as well, which is a major concern. According to those data and the global concern over the increase of air pollution, cruise ship, as well as the Dubrovnik region, are aiming for new solutions in order to decrease emissions and reduce consumption of conventional fuels. AES, SSP and smart energy systems can be seen as potentially good solution. Study [12] presented the result of the Dubrovnik region as a smart energy system aiming to achieve 100% renewable electricity production and total replacement of personal conventional vehicles (LDV) with EVs till 2050. Solar, wind and hydro potential were considered as a potential RES for electricity production. Calculations were done using EnergyPLAN computer program used for the analyses and energy planning of larger energy systems and it works on hourly basis. Results of the study are provided in Table 2.

Table 2 Predictions of the Dubrovnik power system with 100% RES electricity production and total replacement of conventional LDVs with EVs till 2050 [12].

YEAR	2020	2030	2050
ELECTRICITY DEMAND, [GWh/year]	346	408	474
EV CHARGING DEMAND, [GWh/ year]	0.4	21.86	51.43
INSTALLED POWER OF RES, [MW]	102	263	456
CRITICAL EXCESS IN ELECTRICITY PRODUCTION, [GWh/ year]	288.88	646.45	1092.9

Source: A. Šare, G. Krajačić, T. Pukšec, and N. Duić, "The integration of renewable energy sources and electric vehicles into the power system of the Dubrovnik region," Energy. Sustain. Soc., vol. 5, no. 1, 2015.

The results showed that, due to the total replacement of conventional vehicles with EVs, 100% renewable energy system still produces large amount of critical excess of electricity production (CEEP). Excess of electricity production was considered critical since study did not apply any additional storage systems, besides EVs, nor trade market energy system. It can be concluded that the additional energy storage system or other solutions, as trade electricity market and advanced planning algorithms using smart energy system approach should be taken into a consideration in order to reduce high level of CEEP produced by RES. One of the potential solutions, presented within this study, is AES integration with smart energy system of the Dubrovnik region using SSP concept. AES with BESS, can be observed as a potential additional energy storage system using electric batteries on-board, as well as providing electricity to the grid through SSP concept. Smart energy system planning of the Dubrovnik energy system should consider good EMS and planning tools in order to ensure stability and flexibility of multiple energy flows and the entire system. This solution would affect the reduction of conventional fuel consumption and air emissions at sea, in port and land. AES could also help the integration of intermittent RES into the Dubrovnik smart energy system reducing CEEP. RES have variable electricity production therefor aiming for new solutions to enable its integration. Ships, when on berth, can be charged during the night when there is higher production form the wind or during the they when we have higher production from sun, as well as provide electricity to the grid in the time of lack electricity from the grid. In this way they can help with CEEP reduction, providing stability to the grid. With the development of smart energy system applications and higher use of RES in electricity production, today's high costs of the presented system may be significantly reduced in the future ensuring competitiveness of AES, RES and electric batteries on the trade market.

5. CONCLUSION

Emissions from ships are shown to have a high negative impact on the environment and human health, especially cruise ships. Previous studies showed that the emissions from cruise ships in ports are much higher than their entire car fleet. Electric propulsion, shown to have best application in passenger ships, enabled ships to apply AES concept. AES provides ships the use of RES as their energy source aiming to reduce emission and fuel consumption. Through SSP concept, AEC can help the integration of RES in smart energy system due to their large storage capacity. The example of the Dubrovnik region, presented within this work, discussed AEC and SSP concept as a potential solution for CEEP reduction. Although we discussed cruise ships as a potential solution, local ships and ferries can also find their place in this concept, helping the integration of RES on islands.

AEC and SSP have many barriers such as the lack of grid capacity, high initial investment costs, market distortion because of taxation, limited connections available in ports and other. These barriers be can overcome by encouraging the development of smart energy system and SSP concept and electricity production from RES, as well as introducing higher restriction on GHG emissions.

Future work will include analyses of the proposed solution, using energy plan models, and question the potential of local maritime infrastructure for the proposed concept.

REFERENCES

[1] K. Yiğit and B. Acarkan, "The Importance of Ships in the Next-Generation Electric Power Systems," in *Exergetic, Energetic and Environmental Dimensions*, 2017, pp. 167–178.

[2] N. L. Trivyza, A. Rentizelas, and G. Theotokatos, "Impact of carbon pricing on the cruise ship energy systems optimal configuration," *Energy*, pp. 952–966, 2019.

[3] M. E. A. Uusitalo, J. Nerg, A. Groonman, S. Nikkanen, "Numerical analysis on utilizing excess steam for electricity production in cruise ships," vol. 209, pp. 424–438, 2019.

[4] M. Feenstra, J. Monteiro, J. T. van den Akker, M. R. M. Abu-Zahra, E. Gilling, and E. Goetheer, "Ship-based carbon capture onboard of diesel or LNG-fuelled ships," *Int. J. Greenh. Gas Control*, vol. 85, no. March, pp. 1–10, 2019.

[5] S. Jafarzadeh and I. Schjølberg, "Operational profiles of ships in Norwegian waters: An activity-based approach to assess the benefits of hybrid and electric propulsion," *Transp. Res. Part D Transp. Environ.*, vol. 65, pp. 500–523, 2018.

[6] W. Lhomme and J. P. Trovão, "Zero-emission casting-off and docking maneuvers for series hybrid excursion ships," *Energy Convers. Manag.*, vol. 184, no. September 2018, pp. 427–435, 2019.

[7] B. Goldsworthy and L. Goldsworthy, "Assigning machinery power values for estimating ship exhaust emissions: Comparison of auxiliary power schemes," *Sci. Total Environ.*, vol. 657, pp. 963–977, 2019.

[8] C. C. A. Faig Abbasov, Thomas Earl, Nicolas Jeanne, Bill Hemmings, Lucy Gilliam, "One Corporation to Pollute Them All," *Transp. Environ.*, no. June, 2019.

[9] J. Hou, Z. Song, H. Park, H. Hofmann, and J. Sun, "Implementation and evaluation of real-time model predictive control for load fluctuations mitigation in all-electric ship propulsion systems," *Appl. Energy*, vol. 230, no. February, pp. 62–77, 2018.

[10] J. J. De-Troya, C. Álvarez, C. Fernández-Garrido, and L. Carral, "Analysing the possibilities of using fuel cells in ships," *International Journal of Hydrogen Energy*, vol. 41, no. 4. pp. 2853–2866, 2016.

[11] F. Balsamo, C. Capasso, G. Miccione, and O. Veneri, "Hybrid Storage System Control Strategy for All-Electric Powered Ships," in *Energy Procedia*, 2017, vol. 126, pp. 1083–1090.

[12] A. Šare, G. Krajačić, T. Pukšec, and N. Duić, "The integration of renewable energy sources and electric vehicles into the power system of the Dubrovnik region," *Energy. Sustain. Soc.*, vol. 5, no. 1, 2015.

[13] L. Styhre and H. Winnes, "Emissions From Ships in Ports," in *Green Ports*, no. X, Elsevier Inc., 2018, pp. 109–124.

[14] B. Dragović, E. Tzannatos, V. Tselentis, R. Meštrović, and M. Škurić, "Ship emissions and their externalities in cruise ports," *Transp. Res. Part D Transp. Environ.*, vol. 61, pp. 289–300, 2018.

[15] B. Taylor, P. Gaffney, and W. Nickerson, “A holistic approach to the all-electric ship,” *IFAC Proc. Vol.*, vol. 37, no. 10, pp. 191–196, Jul. 2004.

[16] Q. Ji and G. Liu, “A starting method of ship electric propulsion permanent magnet synchronous motor,” in *Procedia Engineering*, 2011, vol. 15, pp. 655–659.

[17] C. og Lim, B. cheol Park, J. chul Lee, E. S. Kim, and S. chul Shin, “Electric power consumption predictive modeling of an electric propulsion ship considering the marine environment,” *Int. J. Nav. Archit. Ocean Eng.*, vol. 11, no. 2, pp. 765–781, 2019.

[18] J. Hou, J. Sun, and H. Hofmann, “Control development and performance evaluation for battery/flywheel hybrid energy storage solutions to mitigate load fluctuations in all-electric ship propulsion systems,” *Appl. Energy*, vol. 212, no. January, pp. 919–930, 2018.

[19] J. Hou, J. Sun, and H. Hofmann, “Adaptive model predictive control with propulsion load estimation and prediction for all-electric ship energy management,” *Energy*, vol. 150, pp. 877–889, 2018.

[20] T. A. Rodrigues, G. S. Neves, L. C. S. Gouveia, M. A. Abi-Ramia, M. Z. Fortes, and S. Gomes, “Impact of electric propulsion on the electric power quality of vessels,” *Electr. Power Syst. Res.*, vol. 155, pp. 350–362, 2018.

[21] Z. Jianyun, C. Li, X. Lijuan, and W. Bin, “Bi-objective optimal design of plug-in hybrid electric propulsion system for ships,” *Energy*, vol. 177, pp. 247–261, 2019.

[22] A. A. Silva, S. Gupta, A. M. Bazzi, and A. Ulatowski, “Wavelet-based information filtering for fault diagnosis of electric drive systems in electric ships,” *ISA Trans.*, vol. 78, pp. 105–115, 2018.

[23] F. D. Kanellos, A. Anvari-Moghaddam, and J. M. Guerrero, “A cost-effective and emission-aware power management system for ships with integrated full electric propulsion,” *Electr. Power Syst. Res.*, vol. 150, pp. 63–75, 2017.

[24] G. S. Misyris, A. Marinopoulos, D. I. Doukas, T. Tengnér, and D. P. Labridis, “On battery state estimation algorithms for electric ship applications,” *Electr. Power Syst. Res.*, vol. 151, pp. 115–124, 2017.

[25] B. Zahedi, L. E. Norum, and K. B. Ludvigsen, “Optimized efficiency of all-electric ships by dc hybrid power systems,” *J. Power Sources*, vol. 255, pp. 341–354, 2014.

[26] A. A. Saad, S. Faddel, T. Youssef, and O. Mohammed, “Small-signal model predictive control based resilient energy storage management strategy for all electric ship MVDC voltage stabilization,” *J. Energy Storage*, vol. 21, no. September 2018, pp. 370–382, 2019.

[27] X. Feng, K. L. Butler-Purry, and T. Zourntos, “Real-time electric load management for DC zonal all-electric ship power systems,” *Electr. Power Syst. Res.*, vol. 154, pp. 503–514, 2018.

[28] W. Zhu, J. Shi, and S. Abdelwahed, “End-to-end system level modeling and simulation for medium-voltage DC electric ship power systems,” *Int. J. Nav. Archit. Ocean Eng.*, vol. 10, no. 1, pp. 37–47, 2017.

[29] S. Castellan, R. Menis, A. Tessarolo, F. Luise, and T. Mazzuca, “A review of power electronics equipment for all-electric ship MVDC power systems,” *International Journal of Electrical Power and Energy Systems*, vol. 96, no. January 2017. Elsevier, pp. 306–323, 2018.

OPTIMAL CONTROL OF GENERATOR SET WITH PERMANENT MAGNET SYNCHRONOUS MACHINE

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Summary

Generators set with permanent magnet synchronous machine (PMSG) are widely used in the construction of power plants for autonomous objects in hybrid vehicles, wind turbines, aircraft and ship installations [4, 16]. Problems of optimal design of the mentioned systems include the following tasks: 1. Structural and technological optimization of electric machines, including transition to modular designs using new materials with stored magnetic energy (samarium-cobalt, neodymium-iron boron). 2. Development of electromechanical modules combining of electric machines, power electronics and microprocessor technology elements to optimize the dynamic and energy characteristics of the systems, to unite energy sources with different parameters into a common network and to exclude the exchange of vibrational power processes. 3. Creation of intelligent systems and networks (Smart Grid), optimized by energy and dynamic characteristics. In this article the mechatronic system containing PMSG and active rectifier (AR) is investigated. This system makes it possible to build of direct current network in which the direct voltage of the load is supported by AR [6]. In the article is consider the possibility of reducing losses in semiconductor converter (AR) and in electric machine by regulating the reactive power in the loop "PMSG-AR". These issues are being addressed in practice through advances in electromechanics, semiconductor and microprocessor technology.

Keywords: permanent magnet synchronous machine, active rectifier, DC power grids, energy optimization

1. INTRODUCTION

Generators set with permanent magnet synchronous machine are widely used in the construction of power plants for autonomous objects in hybrid vehicles, wind turbines, aircraft and ship installations [2, 4, 13, 14]. In recent years, when building energy systems, more and more preference has been given to DC power grids [1, 5, 8, 9, 12, 15]. Without stopping at all the advantages and disadvantages of AC and DC power grids, we will note only a few features of the latter:

- in DC networks easier to solve problems of the separation of power between the generators,
- in DC networks easier to solve problems using different types of generators running on a one network,
- in DC networks easier to solve problems to protect people from electric shock, and object from fires and explosions.

In this article the mechatronic system containing PMSG and active rectifier (AR) is investigated. This system makes it possible to build of direct current network in which the direct voltage of the load is supported by AR [6]. In the article is consider the possibility of reducing losses in semiconductor converter (AR) and in electric machine by regulating the reactive power in the loop "PMSG-AR". These issues are being addressed in practice through advances in electromechanics, semiconductor and microprocessor technology.

The block diagram of the entire generating set is shown in Figure 1, where it is indicated:

- ICE - is an internal combustion engine,
- PMSG-is an synchronous machine with permanent magnets on rotor,
- AR - is an active rectifier,
- CSAR - is an active rectifier control system,
- C, H - condenser of filter (C) in the load circuit (L).

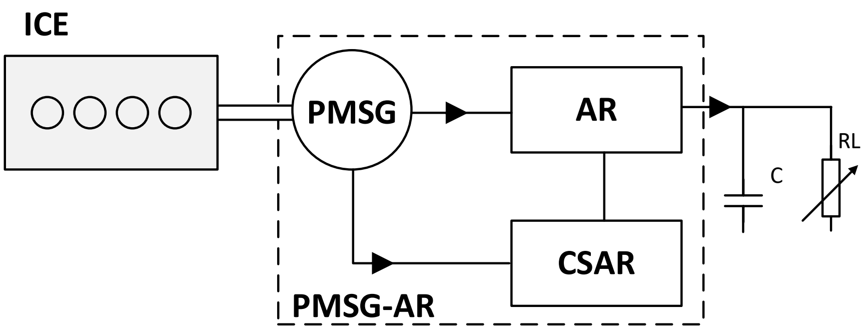

Figure 1 Block diagram of the generator set

2. MATHEMATICAL DESCRIPTION OF PMSG

Further studies below are carried out for the laboratory installation, where the parameters of the machine are shown in Table 1.

Table 1 Parameters PMSG

Parameters	Nominal torque	Nominal speed	Resistance armature	Inductance armature.	The number of pairs poles	EMF Constant	Inertia	DC voltage
	Nm	1/s	Ohm	H		Vs	Kgm^2	V
	100	150	0.6	0.00635	2	0.987	2	600

Electromagnetic processes in the system are investigated on the basis of the equivalent scheme. The scheme is presented in Figure 2 [6]. In this equivalent circuit AR is represented by a controlled voltage source (U_1) that is connected in parallel to the stator windings of PMSG with E_1. Inductive and active resistance in the equivalent circuit are internal parameters of the machine.

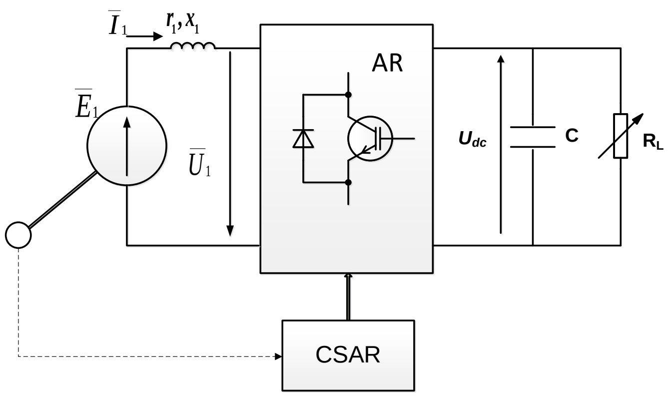

Figure 2 The equivalent scheme of mechatronic system

Source: Based on [6]

Mathematical description of PMSG is carried out in a synchronously rotating coordinate system (*x, y*) using the generalized (resulting) vector method [8, 10, 14] and the "main component" method [3]. This mathematical description looks like:

$$\overline{E}_G(t) = \overline{U}_1(t) + L_1 \frac{d\overline{I}_1(t)}{dt} + r_1\overline{I}_1(t) + jx_1\overline{I}_1(t) \tag{1}$$

Where: $\overline{E}_G(t) = j\overline{\psi}_0\omega(t)$ - spatial (resulting) vector of eds on the stator windings of VEM;

$\overline{U}_1(t)$ - spatial voltage vector at AV output reduced to AC circuit;

$\overline{I}_1(t)$ - spatial current vector in the machine anchor;

r_1, L_1 - resistance and inductance of machine

$x_1 = \omega L_1$ - the reactive resistance of the machine;

ω - angular frequency of PSC voltage.

In equations (1) $\overline{E}_1(t), \overline{U}_1(t), \overline{I}_1(t)$ - resulting vectors of armature voltage, armature current and excitation field flow coupling, In the quasi-established mode, the system of equations (1) is transformed to a form:

$$\overline{E}_1 = \overline{U}_1 + r_1\overline{I}_1 + jx_1\overline{I}_1 \tag{2}$$

In the mathematical description (2) the vectors of state variables are use in a vector diagram to estimate the energy properties of PMSG. When constructing a vector diagram according to equation (2), electromagnetic processes in the PMSG are considered in the system of rotating coordinates (*d, q*) related to the construction of the machine [8, 14], and electromagnetic processes in the AR are considered in the rotating coordinate system x, y related to the voltage and current in the load. In this case, the flow vector $\overline{\psi}_0$ is combined with the zero state of the rotor position sensor (RPS) and is directed along the real axis (d) rotating at the speed of the coordinate system. In this case, the EMF rotation $\overline{E}_1 = j\overline{\psi}_0\omega$ is 90 degrees ahead of the $\overline{\psi}_0$ and will be directed along the imaginary q-axis. Therefore, when building a vector diagram, it is necessary to take into account the fact that the direction of one of the state vectors (voltage or current) is determined by the initial installation of DPR. Vector diagram reflects the physics operation of PMSG and allows you to qualitatively assess the properties of the generator, which depends on both the parameters of the machine itself and the way of construction and the algorithm of active rectifier control.

Below we consider the way of controlling the machine, in which the active rectifier acts as an control current source.

Similar analysis has been conducted for PMSG with the parameters presented in the Table 2:

Table 2 Parameters of the PMSG

Parameters of PMSG	Symbol	Unit	Size
Nominal phase voltage	U_n	V(rms)	220
Resistance of armature winding	r_S	Ω	0.05
Longitudinal armature induction	L_d	mH	0.635
Longitudinal armature induction	L_q	mH	0.635
Number of pole pairs	p	-	4
Number of phases	m	-	3

3. ENERGY CHARACTERISTICS OF THE GENERATOR SET WITH PMSG

In general case for control from the current source the vector diagram of PMSG in the generator mode is shown in Figure 3.

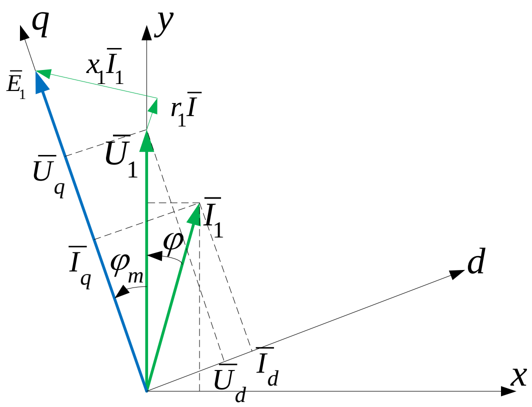

Figure 3 Vector diagram of the generator with PMSG

If the power semiconductor converter uses current control [, the control signals are currents I_d^* and I_q^* the longitudinal and transverse components of the voltage are determined from equations:

$$
\begin{aligned}
U_\mathrm{d} &= -r_1 I_d^* + x_1 I_q^*, \\
U_\mathrm{q} &= -r_1 I_q^* - x_1 I_d^* + \psi_0 \omega.
\end{aligned}
\tag{3}
$$

Energy characteristics of PMSG are calculated by equations:

$$P_1 = \frac{3}{2}(U_d I_d^* + U_q I_q^*),$$
$$Q_1 = \frac{3}{2}(U_q I_d^* - U_d I_q^*), \quad (4)$$
$$P_G = \frac{3}{2} E_q I_q^*, \ Q_G = -\frac{3}{2} E_q I_d^*,$$

Figure 4 shows the results of calculation of energy characteristics, which are presented by the dependencies of active and reactive power at the PMSG output on control signals. Power surface projections on the main plane represent the dependencies between these control signals, at which the power is constant.

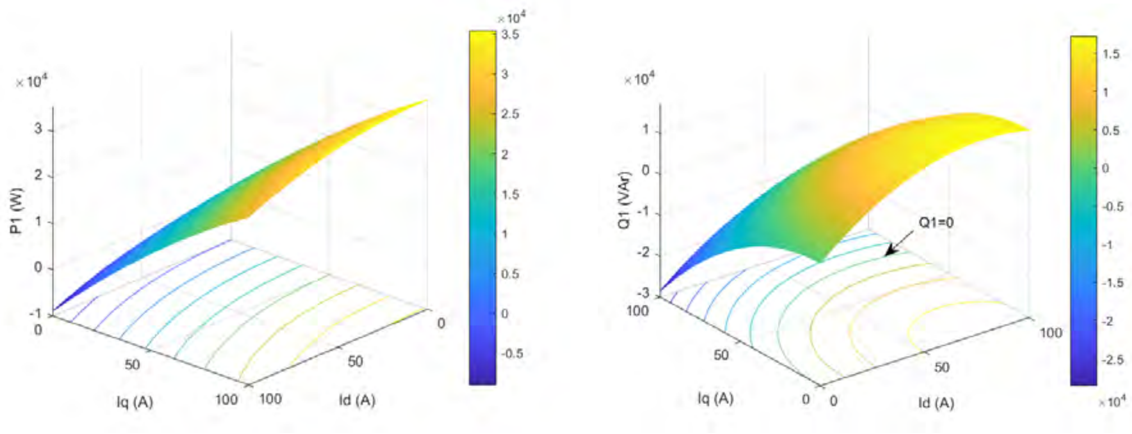

Figure 4 Energy characteristics of the generator with current control

The received power characteristics at current control of PMSG allow to estimate properties of system which are reduced to the following:

- the active power in the PMSG load in the generator mode depends mainly on the current component I_q and insignificantly on the component I_d ;
- the reactive power in the PMSG load is comparable with the active power, which causes an increase in the total current and losses in semiconductor AR devices and PMSG windings;
- in order to maintain zero reactive power in the PMSG load, it is necessary to maintain a certain nonlinear dependence between I_d and I_q;
- the range of control signal change at zero reactive power in the PMSG load for the selected machine is limited by the value $I_q \le 70A$;
- at control only on the active component (I_d = 0) the reactive power in the whole range of change I_q remains negative. In this case, the AR for the PMSG is an active capacitive load.

4. ENERGY CHARACTERISTICS OF AN OPTIMIZED GENERATOR SET WITH PMSG

For optimal control of AR, the voltage and current at the PMSG output coincide in the phase (Figure 5).

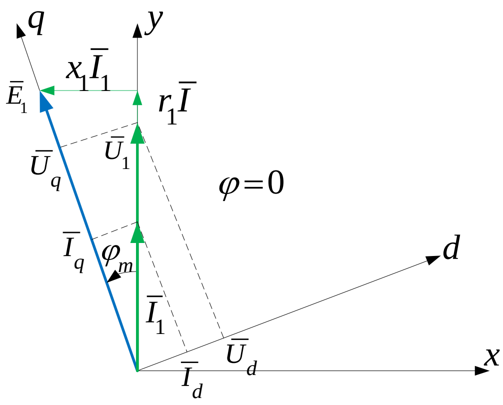

Figure 5 Vector diagrams in the system at zero reactive power in the PMSG load

Then from geometrical constructions (Figure 5), it is possible to define longitudinal and transverse components of currents at which reactive power at the PMSG output is equal to zero.

$$I_d^* = \frac{\Psi_0 \omega}{x_1} \sin^2 \varphi_m,$$
$$I_q^* = \frac{\Psi_0 \omega}{x_1} \sin \varphi_m \cos \varphi_m \quad (5)$$

Calculation of energy characteristics of the generator at such control is carried out by equations (3, 4, 5).

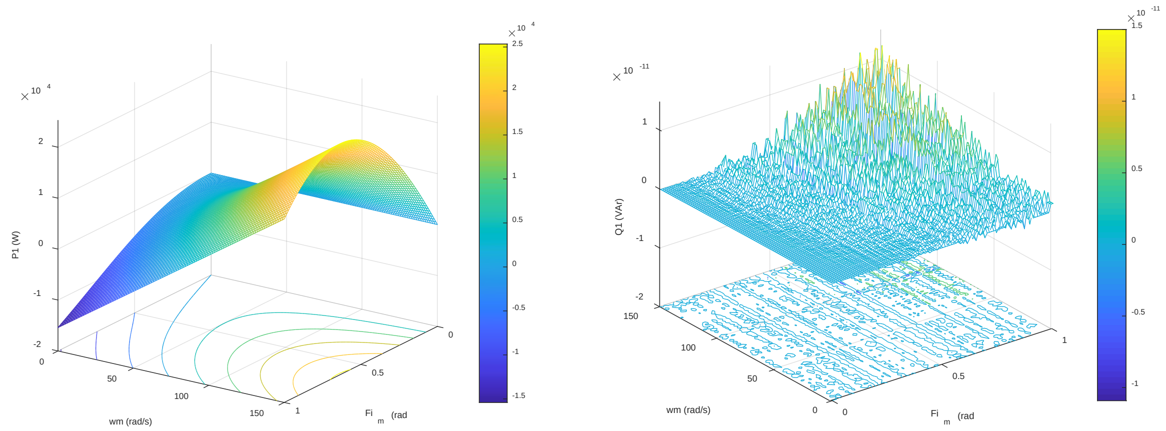

Figure 6 Optimized energy characteristics of the generator

Calculated and constructed energy characteristics of the system are presented in Figure 6, from which it follows that:

- while maintaining the dependence (5), the reactive power at the PMSG output is equal to zero in the whole range of control signals change;
- while maintaining the dependence (5), active power at the PMSG output can be maintained constant at essentially nonlinear dependence between modulation phase and shaft speed of the machine;
- with the increase of power at the PMSG output, the permissible range of changes in the control signals is reduced.

5. MODEL STUDY OF PSMG

Experimental study of the closed-loop generator control system was carried out in Matlab-Simulink environment. The model of the generator with PMSG is shown in Figure 7. In the structure under consideration, the internal combustion engine is controlled by a speed regulator. In this mode, the speed of the PMSG shaft is specified and the main requirement to its electrical part is to maintain a constant voltage in the DC link when changing the electrical load. Voltage stabilization is carried out in a classical system control with a PID regulator.

The signal from the output of the PID regulator is fed to the functional converters (Fcn6, Fcn7 - Figure 7). In converters carry out calculate the reference currents according to the equation (5). Modulation phase is defined in block Fcn10 (Figure 7) by the equation.

$$\varphi_m = arctg \frac{U_d}{U_q} \tag{6}$$

The system with independent current control, which is described by equation (4), and the system with optimized current control, which is described by equation (5), are compared. Figure 8 and Figure 9 shows the results of modelling of both systems in transient and steady-state modes of operation of the generator set with PMSG. Curves (Figure 8) demonstrate ttransition processes of the active and reactive power at the PMSG output.

In the steady-state mode of operation under load in the system with independent current control ($I_d^* = 0, I_q^* = \text{var}$) the reactive power of PMSG is approximately one third of the active power (Figure 8). In the optimized system, short-term changes in reactive power are observed at the time of load shedding. In the steady-state mode this power is practically equal to zero (Figure 8). Electromagnetic processes in both systems are the same (Figure 9), they are represented by currents in the stator of the machine, the load current in the DC link AV (I_{dc}) and the voltage in the DC link AV (U_{dc}).

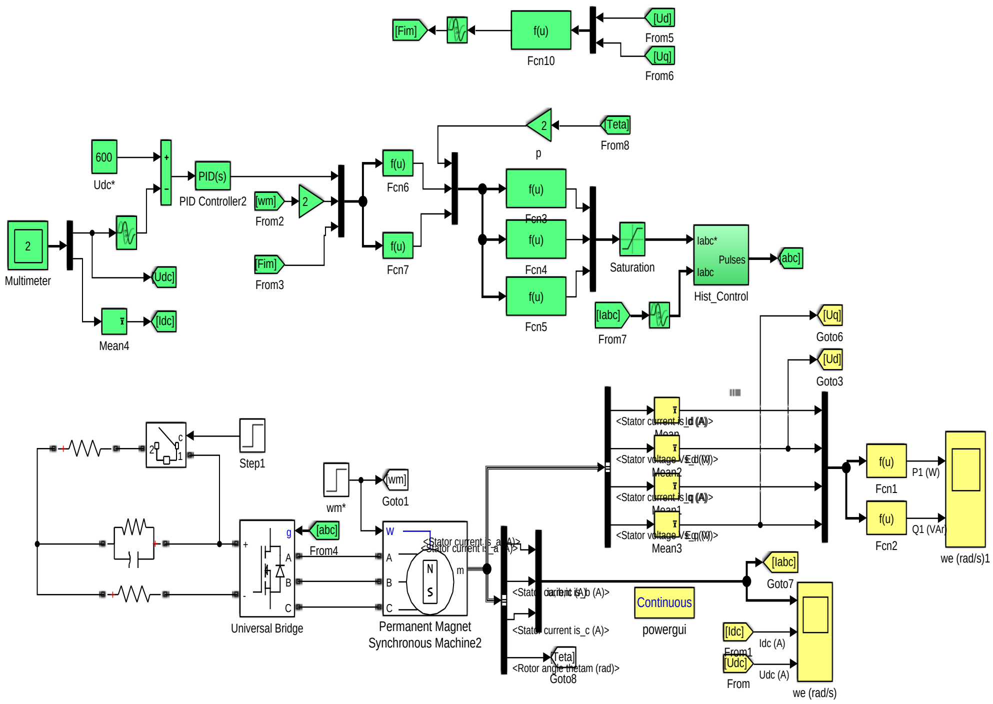

Figure 7 Model of the generator with PMSG

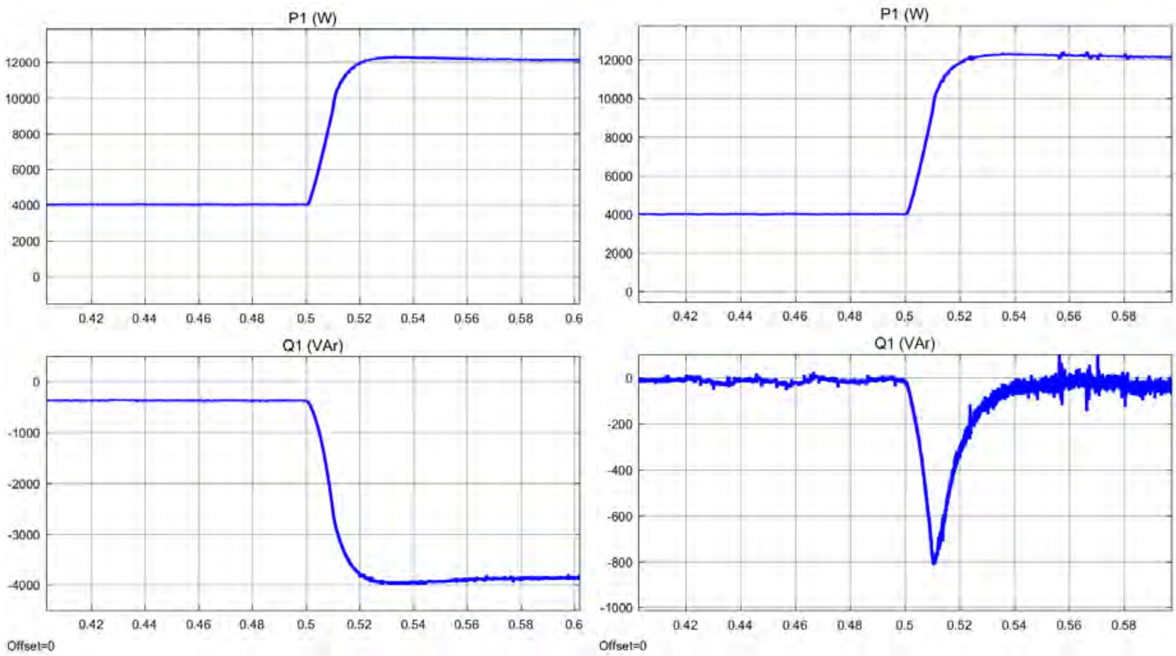

Figure 8 Transition energetics processes in an unoptimized and optimized system when changing the load

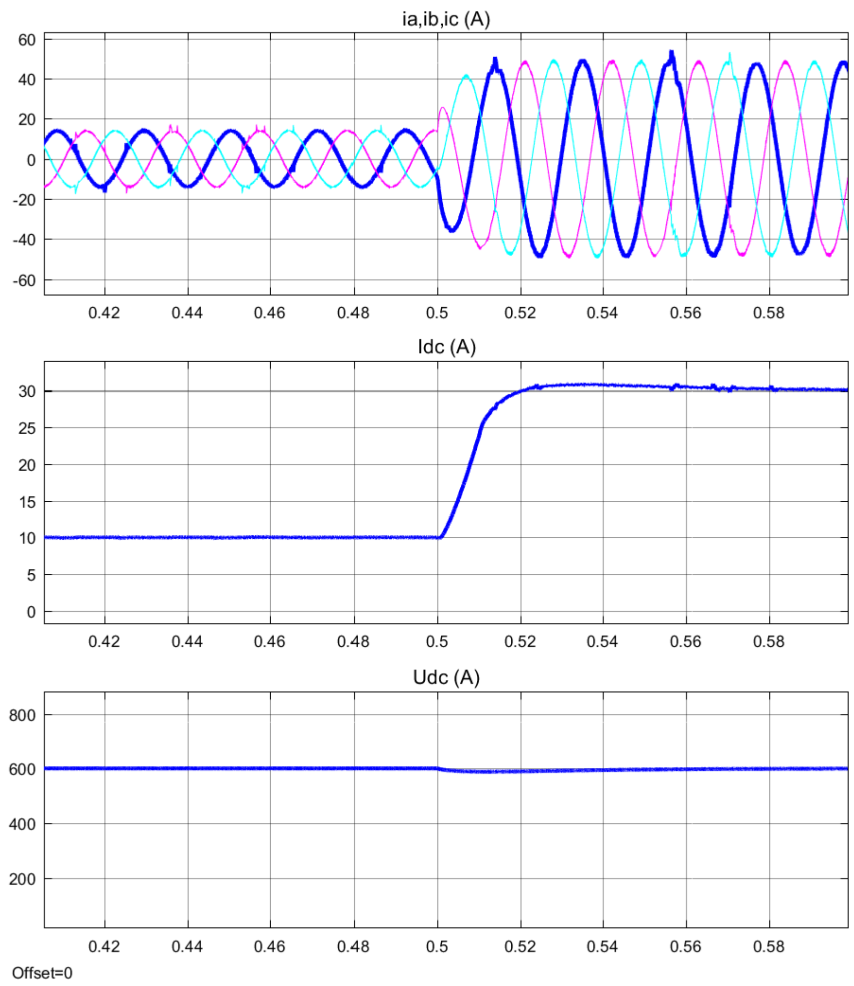

Figure 9 Transition electromagnetics processes in an unoptimized and optimized system when changing the load

The processes presented in Figure 8, Figure 9 show that in the optimized system the change in the generator electrical load does not affect the voltage Figure 9. Curves (Figure 10) are demonstrate transition energetics and electromagnetics processes at the PMSG output when changing the speed from 150 to 100 rad/s of generator shaft.

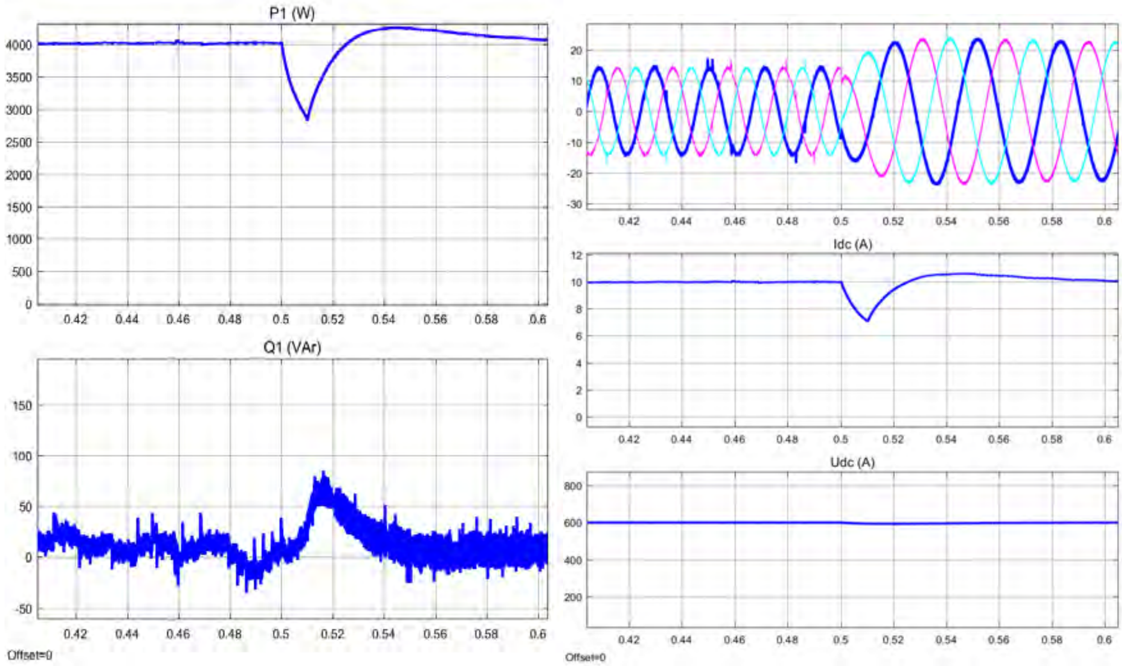

Figure 10 Transition energetics and electromagnetics processes in an optimized system when changing the speed from 150 to 100 rad/s of generator shaft

The results of modeling show that the generator set with PMSG provides the basic requirements - to maintain a constant voltage at changing the current (power) in the load and changing the speed of rotation of the shaft. In addition, with optimal control according to equation (5), the reactive current in the machine is reduced to zero, which reduces the losses in the active resistances of the machine and the active rectifier.

6. CONCLUSION

Reactive currents and, accordingly, losses in the converter and the machine may be several times lower with a certain ratio between the amplitude and the phase of the voltage (current) on the AC side of the AR. Optimization of energy properties of generating sets acquires special importance in the construction of powerful hybrid transport systems and systems of full electric propulsion. These systems have different, comparable in power, sources of electrical energy whose operating on the total variable load. Examples of such objects are land-based, sea, river and air transport, and examples of such sources of electrical energy - diesel generators, shaft generators, steam and turbo generators, batteries, supercapacitors, etc.

ACKNOWLEDGMENT

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REFERENCES

[1] Ahmed, A., Haider, A., Van Hertem, D., Zhang, I. and H. Nee, P., Prospects and challenges of future HVDC Super Grids with modular multilevel converters, Proceedings of the 2011 14th European Conference on Power Electronics and Applications, 30 Aug - 1 Sep 2011, pp. 1-10, Birmingham, United Kingdom, (2011).

[2] Brodovski V. N., Ivanov E. S. Drives with frequency-current control. M.: Energy, 1974.

[3] Bulgakov A. A., New theory of controllable rectifiers, “Science”, Moscow, 1970, pp. 326.

[4] Chan, T., and Lai, L. "Permanent-Magnet Machines for Distributed Power Generation: A Review," IEEE Power Engineering Society General Meeting, Conference Location: Tampa, FL, Added to IEEE Xplore: 23 July 2007, DOI:10.1109/PES.2007.385575

[5] Fazeli, S. M., Jovcic, D., Lin, W.: Distributed Control for LCL DC Hub Enabling Reliable Energy Transfer in Future DC Grids, Published in: 11th IET International Conference on AC and DC Power Transmission, Birmingham, UK, 2015, DOI: 10.1049/cp.2015.0035,

[6] German-Galkin, S.: MATLAB SCHOOL. Virtual laboratory for power electronics and electromechanical devices in Matlab+Simulink software. Lesson 26: Optimization of energetic properties of mechatronic system by means of electric machine with power electronic, Magazine „Power electronics” Vol. 3, No 72, pp. 68-75, 2018, (ISSN 2079-9322).

[7] German-Galkin S., Tarnapowicz D., Tomasov V. S., "The Use of Topology of IHBI Inverters in Parallel Operation of Ship Generating Sets With PMSG Generators," New Trends in Production Engineering, Volume 1: Issue 1, 10 Dec 2018, pp.309-315, DOI 10.2478/ntpe-2018-0038

[8] Gorev, A. A.: Transient processes of synchronous machine, Leningrad - Moscow: State Energy Publishing House (Gosenergoizdat), pp. 552, 1950

[9] Hu, J., Stieneker, M., Joebges, P., Doncker, R.: Intelligent DC-DC Converter Based Substations Enable Breakerless MVDC Grids, Published in: 2018 IEEE Electronic Power Grid (eGrid), Charleston, SC, USA, DOI: 10.1109/eGRID.2018.8598689

[10] Kovacs, K. P., Racz, I.: Transient processes in alternating current machines, Transiente Vorgänge in Wechselstrommaschinen. Verlag der Ungar., Budapest: Akad. der Wissenschaften, 1959.

[11] López-Ortiz, E., N., Campos-Gaona, D., and Moreno-Goytia, E., L. "Modelling of a wind turbine with permanent magnet synchronous generator," IEEE 2012 North American Power Symposium (NAPS), Added to IEEE Xplore: 22 October 2012.

[12] Lu, S., Wang, L., Lo, T., Prokhorov, A.: Integration of Wind Power and Wave Power Generation Systems Using a DC Microgrid, Published in: IEEE Transactions on Industry Applications, Volume: 51 , Issue: 4 , July-Aug. 2015, DOI: 10.1109/TIA.2014.2367102

[13] Ovchinnikov I. E. Permanent Magnet Synchronous Motors and drive on their basis. SPB, Corona - Century St. Petersburg, 2006, ISBN 5-7931-0344-9.

[14] Park, R. H.: Two-reaction Theory of Synchronous Machines—II", AIEE Transactions, vol. 52, June 1933.

[15] Rossa R., E. Krol, "Modern electric machines with permanent magnet.," Przegląd Elektrotechniczny, Volume 84, Issue 12. 2008 pp. 12-17, ISSN: 0033-2097

[16] Semken, R. S., and all, "Direct-drive permanent magnet generators for high-power wind turbines: benefits and limiting factors," Renewable Power Generation, IET , vol.6, no.1, pp.1-8, January 2012

THE INFLUENCE OF SLOW SPEED DIESEL ENGINES CYLINDER LINER TEMPERATURE ON SPECIFIC FUEL CONSUMPTION

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Summary

Presently, the money race and earnings is probably more pronounced than ever before. This is especially noticeable in shipping business, which has been reducing costs for years to remain competitive on the market and earn more profits. It is well known that the largest cost in shipping business are the fuel and lube oil costs. Today, engine power, which directly affects on fuel consumption, is higher than ever, and therefore a slightly change in specific fuel consumption has a major impact on efficiency. Large two stroke slow speed diesel engines have the efficiency slightly above of 50%. The large part of the unused fuel energy are thermal losses through the cylinder liner due to necessary cooling. By increasing the jacket cooling water temperature the cylinder liner temperature increases as well and the heat losses through the jacket could be reduced, and consequently the main engine efficiency increased, that is reduces specific fuel consumption. By calculation method and by using the cylinder liner temperatures mean values has been shown that by increasing the cylinder liner cooling water temperature to 120 ^{0}C, results in saving of approximately 1 [*g/kWh*] on specific fuel consumption, only on losses through the cylinder jacket. The results has been proved by using the slow speed marine diesel engine plant simulator. The engine efficiency increasing and consequently fuel consumption reducing certainly must go through the amount of waste heat energy reducing. One of the way is by increasing the engine cooling media temperature.

Keywords: heat transfer, cylinder liner, specific fuel consumption

1. INTRODUCTION

The maximum combustion temperature[1] of internal combustion engines today is around 2500^{0}C, while the maximum temperatures of metals in contact with such temperatures are limited to much lower values[2] and, therefore, cooling is necessary. Due to such a high temperature differences, very large heat fluxes occurred, which, during combustion, can reach around 10 *MW/m^2*. During the other processes, the heat flux is small or close to zero, or even negative (from cylinder liner to scavenging air). So heat flux varies in intensity, direction, time and space [4].

[1] The temperature duration for a very short period while the process mean temperature is around 800 ^{0}C.
[2] The temperature limits for cast iron are around 400 ^{0}C and for aluminium around 300 ^{0}C.

The greatest cylinder heat flow is in the area where the highest combustion gases temperatures and velocities are. On these areas, it is necessary to maintain the cooling thermal load within acceptable limits. The gas side cylinder liner wall temperature should be maintained below 180^{0}C, in order to maintain a sufficient oil film thickness [4].

The heat transfer affects the engine performance, namely, the efficiency and the emissions. For the same fuel amount brought into the cylinder, a greater heat transfer to the cylinder liner wall (cooling increased) means the pressure and average combustion gas temperature drop, thus reducing the performance and the efficiency [4].

The heat amount, which is transferred to the cooling water through the cylinder liner wall, ranges from 1/3 to 1/4 of the total chemical energy brought into the cylinder by the fuel. Approximately half of this heat is transferred to the walls inside the cylinder while most of the remaining half goes to the wall of the exhaust gas channel, in a case when the channel is not isolated [4].

Large two stroke slow speed diesel engines have the efficiency slightly above of 50%. The large part of the unused fuel energy are thermal losses through the cylinder liner due to necessary cooling. By increasing the jacket cooling water temperature the cylinder liner temperature increases as well and the heat losses through the jacket could be reduced, and consequently the main engine efficiency increased, that is reduces specific fuel consumption.

By calculation method, the reduction in specific fuel consumption will be determined and compared with the data calculated by the simulator.

Since the cylinder liner temperature depends on cooling water temperature, the cooling water temperature will be assumed and increased from 80^{o}C to 150^{o}C. Cylinder liner temperature will be calculated with given parameters, and from there, the heat loss through the cylinder liner will be also calculated.

2. CALCULATION

Since the Kongsberg engine room simulator will be used to verify the results, and it is based on the MAN B&W MC-90 engine, its specifications will be used in the calculation. In this paper local values are of no interest, so all the variables are mean values (geometry, temperatures, pressures…)

As said before, since the cylinder liner temperature depends on temperature of cooling water, its temperature will be assumed in range from 80^{o}C to 150^{o}C in steps of 5^{o}C.

Basic equation for calculation is the one for the cylinder liner temperature:

$$T_{st,sr} = \frac{T_{c,mn} \cdot A_{mn} \cdot \alpha_{k,mn} \cdot \left(\frac{\delta_{st}}{\lambda_{st} \cdot A_{st}} + \frac{1}{\alpha_{cw} \cdot A_{cw}}\right) + T_{cw}}{1 + \left(\frac{\delta_{st}}{\lambda_{st} \cdot A_{st}} + \frac{1}{\alpha_{cw} \cdot A_{cw}}\right) \cdot A_{mn} \cdot \alpha_{c,mn}} \quad [1]$$

Where:

Suffix *mn* – mean values
Suffix *cw* – cooling water
Suffix *st* – cylinder liner wall
λ_{st} – heat conduction of cylinder liner [*W/mK*]
δ_{st} – mean thickness of the cylinder liner [*m*]
$\alpha_{c,mn}$ – mean coefficient of heat transfer and is calculated from the expression:
$\alpha_c = \frac{\int \alpha_{c,i} \cdot A_{c,i}}{A_c}$ [1]

After calculation, graph of cylinder liner temperatures with different cooling water temperatures is made and shown in figure 1.

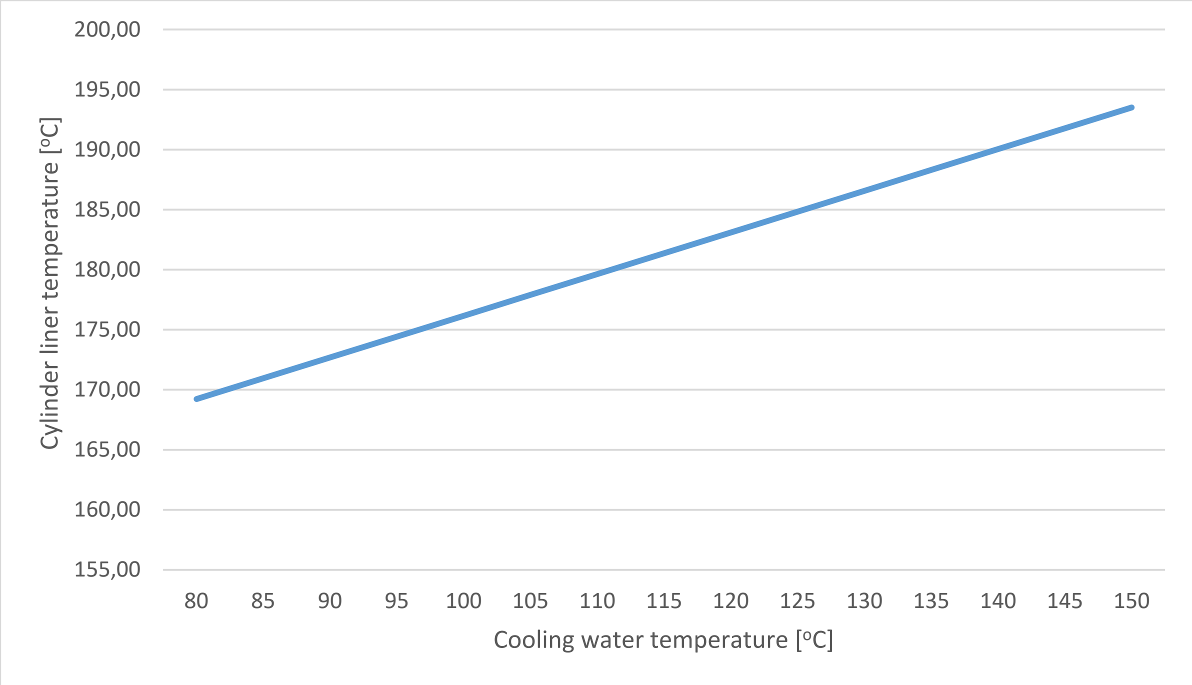

Figure 1 Cylinder liner temperature dependending on cooling water temperature [Authors]

Studies [2] and [3] have found that the cylinder liner walls, piston and cylinder head temperature in a stationary mode is a constant one, so that the mean surface temperature can be counted on. The heat transfer coefficients difference over the cylinder liner surface can be ignored, for the purpose of this study, and the mean heat transfer coefficient accepted [4].

The convection heat transfer speed can be expressed as:

$$\frac{dQ_{st}}{d\varphi} = \sum_{i=1}^{n} \alpha_{\kappa} \cdot A_{st} \left(T_{st,i} - T_C\right) \frac{dT}{d\varphi},$$

and this equation could be used for researching heat transfering throught the cylinder liner for each crank angle. Such approach requires knowledge of the cylinder liner wall temperature at its full height which will not be the subject of this work.

With the cylinder liner temperatures known, heat taken away by the cooling water can be calculated by the equation:

$$Q_o = \alpha_k \cdot A_c \cdot (T_c - T_{st,sr})$$

The referent heat taken away is the one taken with the cooling water at 80°C. For every other cooling water temperature, consequently every other cylinder liner temperature, heat taken away is deducted from this referent heat.

$$\Delta Q_o = Q_{o,80} - Q_{o,i}$$

Difference is the heat that is used to produce work in the engine. If added to the nominal power, power specific to that cylinder liner temperature is calculated.

In order to calculate specific fuel consumption, absolute fuel consumption per hour needs to be calculated:

$$F = Sfc \cdot P_n$$

Where:

Sfc – specific fuel consumption for normal operation (cooling water temperature of 80°C), known from manufacturers specifications.

P_n – nominal power, also known from manufacturers specifications.

Now, new power with reduced heat loss is calculated:

$$P_i = P_n + \Delta Q_o$$

Since the overall consumption by hour has not changed, new specific fuel consumption is calculated:

$$Sfc_i = \frac{F}{P_i}$$

The results are shown in the graph below:

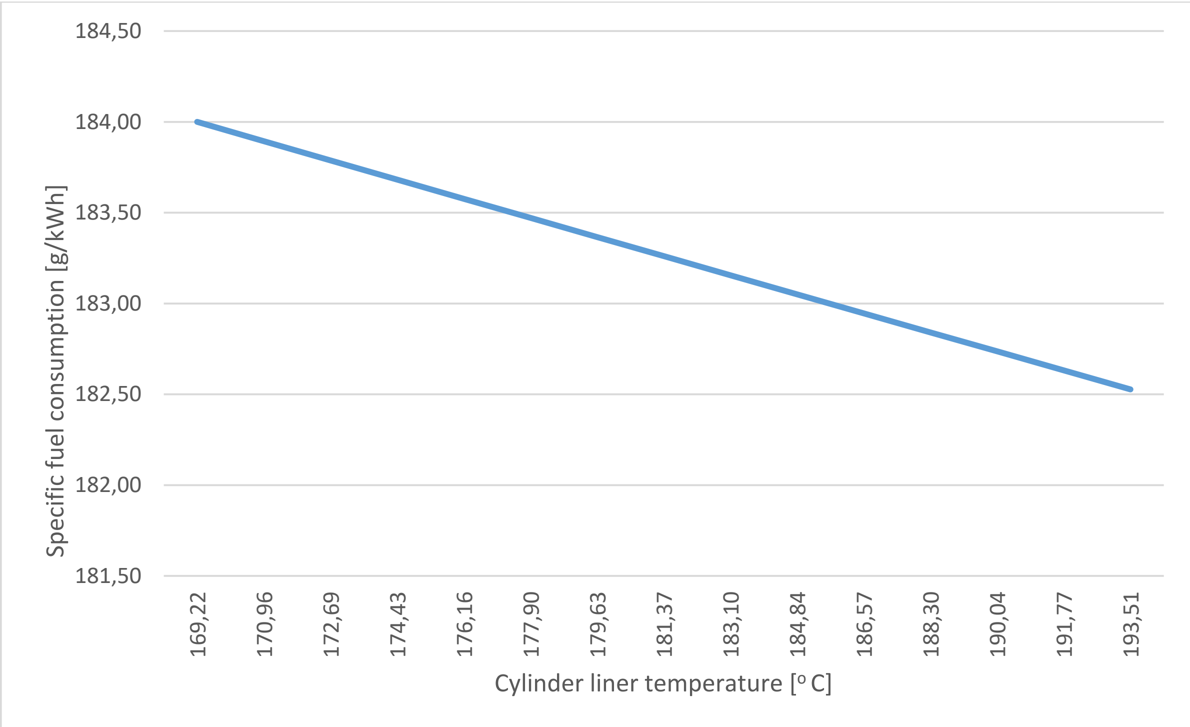

Figure 2 Specific fuel consumption dependency on cylinder liner temperature [Authors]

3. SIMULATING RESULTS ON KONGSBERG ENGINE ROOM SIMULATOR

In order to validate the calculated results several simulations have been made on Kongsberg Engine Room Simulator. Since there is no way to directly change the temperature of the cylinder liner, the temperature of cooling water was changed. It was made on the cooling water temperature regulator, and trend graph has been made.

Figure 3 Trend of specific fuel consumption dependency on cylinder liner temperature on Kongsberg simulator [Kongsberg Norcontrol Engine Room Simulator]

Checking the cylinder liner temperature along with specific fuel consumption:

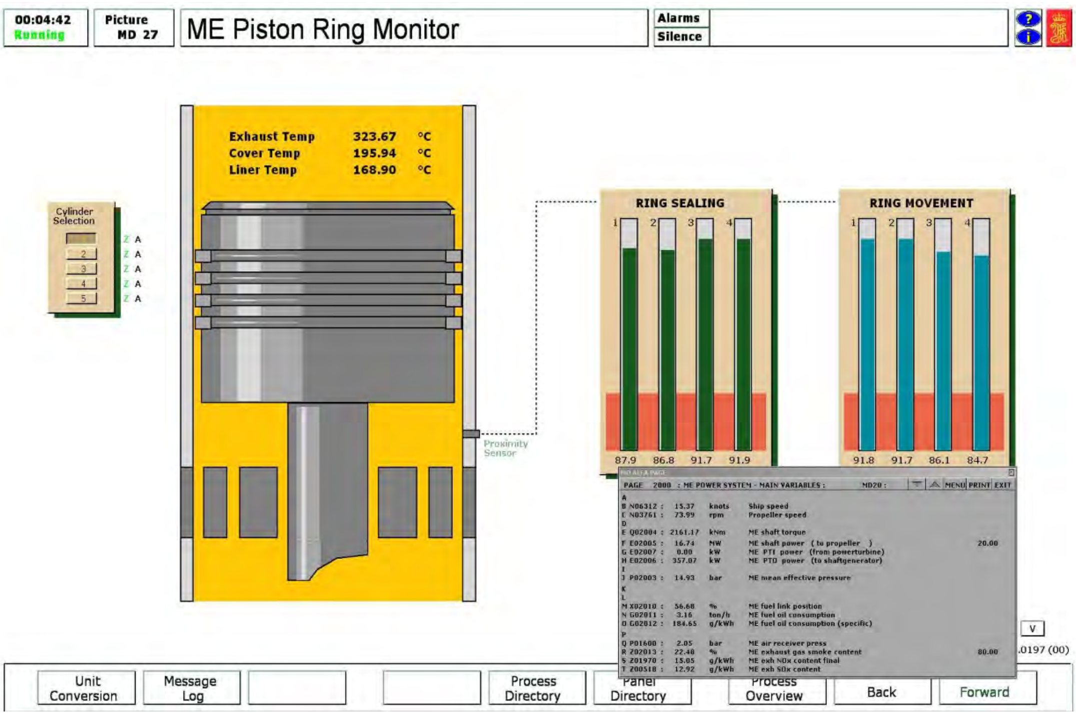

Figure 4 In cylinder variables along with engine parameters [Kongsberg Norcontrol Engine Room Simulator]

Simulations could not be made in such way that only cylinder liner is affected by the cooling water temperature change. Along with the cylinder liner, the cylinder head, piston head, and exhaust valve have heated up. Because of that the results are much better than in the calculation (181,5 g/kWh opposed to 183,2 g/kWh). So in order to compare the results trend line is crucial. Besides trend line, the overall amount of cooling water per hour that circulated around the engine is known, so additional calculation was made. It was the calculation of heat that was taken by that amount of cooling water and and results were compared to the results given by the calculation and Kongsberg simulator.

Mass (*m*) of water circulating through the system is gathered from the Kongsberg simulator, for the cooling water temperature of 80°C and 115°C as seen below:

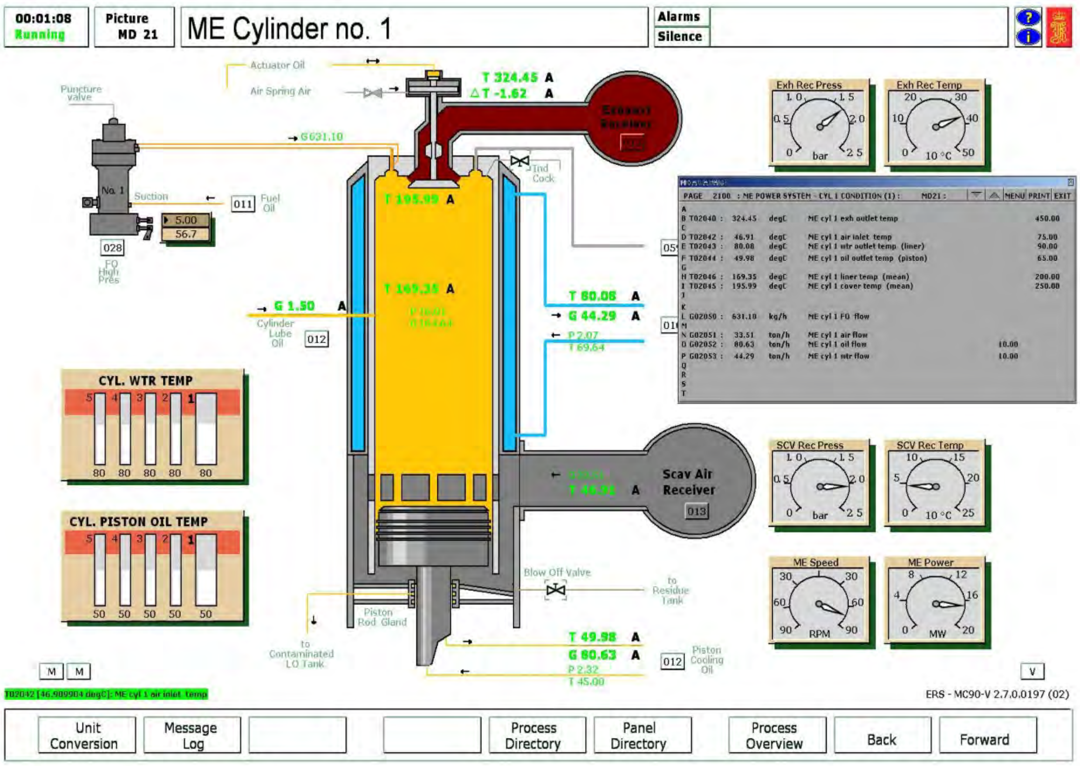

Figure 5 Cooling water parameters [Kongsberg Norcontrol Engine Room Simulator]

Specific heat capacity of water is known constant, and it is *Sp* = 4200 *J/kgK*.

And the last variable is temperature change (*Δt*), which is also read from the simulator (temperature of the cooling water entering the engine is deducted from the temperature of the cooling water exiting the engine).

Finally, the equation for heat taken away by water (Q):

$$Q = Sp \cdot m \cdot \Delta t$$

Since the data obtained from the Kongsberg simulator is per hour (mass of water), given result must be divided by 3600 to reduce it to seconds.

Now, heat taken away by cooling water at 115°C (or at any other temperature) can be deducted from the heat taken away by cooling water at 80°C (ΔQ).

Since the original calculation is made for one cylinder, and here is the mass of cooling water for whole the engine, result must be divided by 5, since in the Kongsberg simulator engine has 5 cylinders.

Given result is then again added to nominal power:

$$P_i = P_n + \Delta Q$$

And new specific fuel consumption can be calculated as earlier:

$$Sfc_i = \frac{F}{P_i}$$

The result is 182,14 g/kWh, which concurs results read from the Kongsberg simulator, and aligns with calculated results.

To get an idea about quality of calculated results, statistical coefficients R^2 and RMSE were calculated for specific fuel consumption.

R^2	0,9734
RMSE	0,6291

Although those coefficients look quite good, it is not really the best way of comparing results since in the calculation only heat transfer through the cylinder liner is taken into consideration, and simulation is much more complex and takes into consideration heat losses through cylinder head, exhaust valve, piston… For that reason, as temperature of the liner gets higher, the bigger is the difference between analised methods.

It should be noted that during simulation some issues occurred. After reaching 100°C, the cooling water began to evaporate. Since cooling water system on this large two stroke diesel engine plant is opened, unlike the cooling water system in regular modern cars, the water is free to evaporate. For simulation purposes the problem was solved by adding water to expansion tank. That worked to a temperature of cooling water of about 115°C. Higher than that was not possible. It is important to emphasise that this fix was just for the simulation purposes, and would not be economical for everyday use.

4. CONCLUSION

New ways of saving fuel is a priority for many reasons. Mainly the cost reduction and preservation of environment. Every gain in savings in fuel consumption is a large success. Reduction of heat losses through engine parts is definitely the way in which significant savings can be made. Results in this paper confirmed that with increased cooling water temperature even 5% of fuel can be saved. Of course, like everything else it comes with a cost. First problem that emerges is evaporation of cooling water. With that problem solved (closed cooling water circuit?, higher expansion tank position?), there could emerge other problems like material threshold for given temperatures, oil temperature sensitivity, gasket sensitivity…

All this problems can be solved, but at what cost?

REFERENCES

[1] Bernečić, D., Analiza utjecaja višestrukog ubrizgavanja na procese i produkte izgaranja u sporookretnom brodskom dizelskom motoru, Sveučilište u Rijeci, Pomorski fakultet, Rijeka 2011.

[2] Woschni, G.: *Die Berechtung der Wandverluste und thermischen Belastung der Bauteile von Dieselmotoren*, MTZ 31 (1970) 12, 491-499.

[3] Löhner, K., Döhring, E., Chore, G.: *Temperaturschwingungen an der Innenwand von Verbrennungskraftmaschinen*, MTZ, Nr. 12, 1956.

[4] Bernečić, D., Šegulja, I., Heat transfer influence analysis on combustion pressure in two-stroke slow-speed marine diesel engines, Pomorstvo, br.1/2013., 73 – 85.

ANALYSIS OF CARGO SHIPS ACCIDENTS IN THE PAST DECADE

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Summary

Safety at sea is a major concern of all maritime transport stakeholders. There is a need to recognize risks at sea in order to reduce number of accidents and improve overall safety in shipping. One way to achieve that goal is to analyse maritime accidents and unveil consequences that lead to unwanted dangerous occurrences. Authors analysed cargo ships accidents recorded in MAIB database that occurred during the last decade. Types of ships analysed were bulk carriers, general cargo vessels, container vessels, Ro-Ro vessels and tankers. It was found that general cargo vessels and Ro-Ro vessels were the most endangered types of cargo vessels since they were involved in most of the accidents.

Keywords: accident, safety, vessel

1. INTRODUCTION

Safety of ships at sea is main concern of all maritime traffic stakeholders. Lack of safety can induce loss of lives, environment pollution, damage to cargo and/or vessel, and it needs to be avoided [1]. International Maritime Organization (IMO) focused on improving safety on board ships through different sets of rules, regulations and requirements. Improvements are visible in ships design, stability, propulsion, equipment and human elements (organization and decision making). Conventional vessels design aims at a structure that has a strength capacity higher than the minimum required in order to avoid structural failure from operational loads and environmental loads [2]. Even though inspections of vessels are stringent and substandard vessels are kept in detention or prohibited to continue with operation, number of maritime accidents is still large [3].

Maritime accident as per IMO's "Casualty Investigation Code" in its updated version and IMO Circular MSC-MEPC.3/Circ.3 is any maritime casualty or incident. An accident does not include an intended act or omission, with the intention to cause harm to the safety of a vessel, persons or the marine environment [4, 5].

Accidents can be classified as [4, 5]:

- Very serious marine casualties
- Serious marine casualties

- Less serious marine casualties
- Marine incidents

Marine casualty is an event, or a sequence of events, that has resulted in any of the following which has occurred directly in connection with the operations of a vessel [4, 5]:

- The death of, or serious injury to a person
- The loss of a person from a vessel
- The loss, presumed loss or abandonment of a vessel
- Material damage to a vessel
- The stranding or disabling of a vessel, or the involvement of a vessel in a collision;
- Material damage to marine infrastructure external to a vessel, that could seriously endanger the safety of the vessel, another vessel or an individual
- Severe damage to the environment, or the potential for severe damage to the environment, brought about by the damage of a vessel or vessels.

Marine incident is an event, or sequence of events, other than a marine casualty, which has occurred directly in connection with the operations of a vessel that endangered, or, if not corrected, would endanger the safety of the vessel, its crew or passengers or any other person or the marine environment. Marine incidents include hazardous incidents and near misses [4, 5].

Human error is accountedfor about 80-85% of all maritime accidents [6]. Since new technologies are introduced in maritime transport lately, some of the factors that can lead to human error are technology complacency and over-reliance to technology [7]. Human factors, shown as the basis of marine accidents, cover all of the actions revealing the relation between people and machines [8]. Human-machine interaction is important safety aspect that needs to be nourished and transformed into strongest link of safety; it must not be marked as a weak link of maritime safety.

Inadequate leadership, absence of teamwork and poor human relations onboard vessels can also lead to human error and induce accidents [9]. IMO addressed that issue and specialized trainings were adopted by STCW 2010 to minimize accidents caused by human factor.

Accidents are usually not caused by single mistake, but by the chain of errors, or when all defences, barriers and safeguards are penetrated.

Several catastrophic accidents occurred in the past decade, such as sinking of container ship *SS El Faro* and cargo ship *Cemfjord* with the worst consequences – total loss and fatalities.

In order to prevent such disasters in future, reduce number of maritime accidents and increase maritime safety, it is needed to reveal root causes of accidents occurred and implement efficient corrective measures. Analysis of maritime accidents will help to reveal most accident prone types of vessels and find ways to increase their safety.

The aim of this paper is to reveal causes and consequences of certain types of vessels maritime accidents and analysis of maritime accident report forms.

For the purpose of this paper authors analysed Marine Accident Investigation Board (MAIB) database.

2. METHOD

MAIB database (accessible online via web – open access) was researched for maritime accidents in order to reveal causes and consequences of the accidents involving cargo ships. Each MAIB accident report constitutes of at least following chapters: summary, factual information, analysis, conclusions, action taken and recommendation. Most interesting chapter for this research was investigation report conclusion where contributing factors as per accident investigators are listed. Research was done in a way that completed accident reports were compiled from year 2009 to 2018.

There were 253 accident reports found in that period, and each of them was read and checked for types of vessel(s) involved, consequences and contributing factors [9]. Authors manually searched accidents involving cargo vessels, namely: bulk carriers, Ro-Ro vessels, container vessels, general cargo vessels and tankers (including oil tankers, LNG, LPG, chemical and product tankers).

For the purpose of the paper authors divided possible causes of maritime accidents into five groups:

1. Human factor,
2. Technical factor,
3. Inadequate procedures and policies,
4. External factors,
5. Unknown.

It is important to stress that some accidents have multiple causes and multiple consequences, for instance, it might be that particular accident was caused by human and technical factors, and had fire and explosion for consequences. In that way number of causes and consequences is higher than number of vessels involved in accidents.

Accident reports in the last decade are analysed according to vessel type, and for each type causes and consequences were identified.

3. ANALYSIS

Accident investigators that prepared accidents reports in MAIB database determined factors that might cause accidents, and then those factors were assigned to one or more of the five factors (human, technical, external, inadequate procedures and policies and unknown) which were recognized as root causes by the authors.

Number of accidents involving chosen types of vessels annually in the last decade is presented in Figure 1.

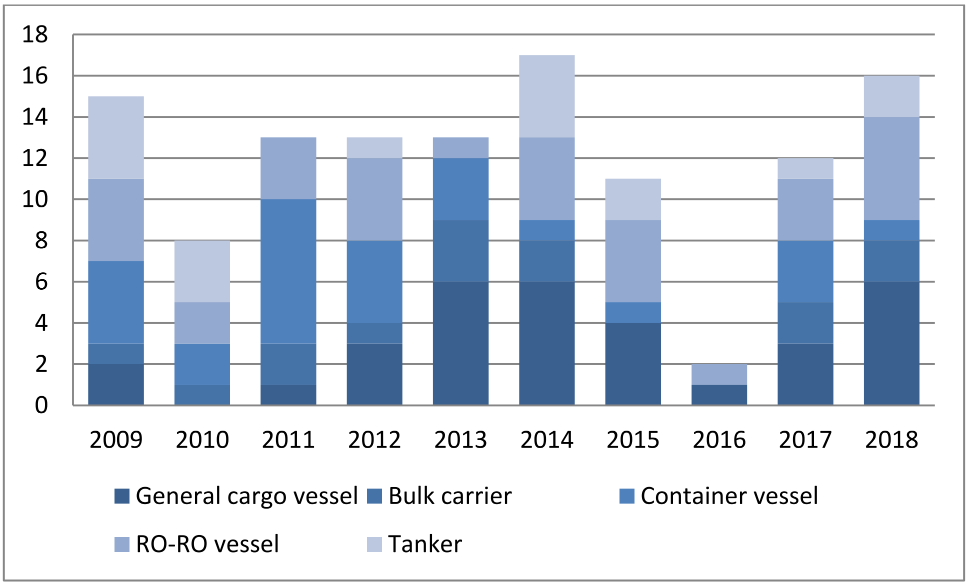

Figure 1 Number of accidents annually according to vessels type in the last decade

Source: Authors

As it can be seen from Figure 1, number of reported and investigated accidents annually is more or less steady, only in year 2016 there is a large decrement with only two accidents investigated. Based on available data from MAIB, it cannot be concluded whether there were two accidents due to safety measures implemented, was it just coincidence, or maybe underreporting of accidents.

Ro-Ro vessels were involved in 31 accidents during last decade. As Figure 2 depicts, grounding and contact were most common consequences, closely followed by collision and fire. Grounding, contact, collision and fire make 64% of all consequences of Ro-Ro vessels accidents. Reasons for groundings and contacts of Ro-Ro vessels could be due to fact that they are usually plying on short relations and frequently perform operations of entering and leaving ports, navigation in confined waters and dense traffic in those areas [9].

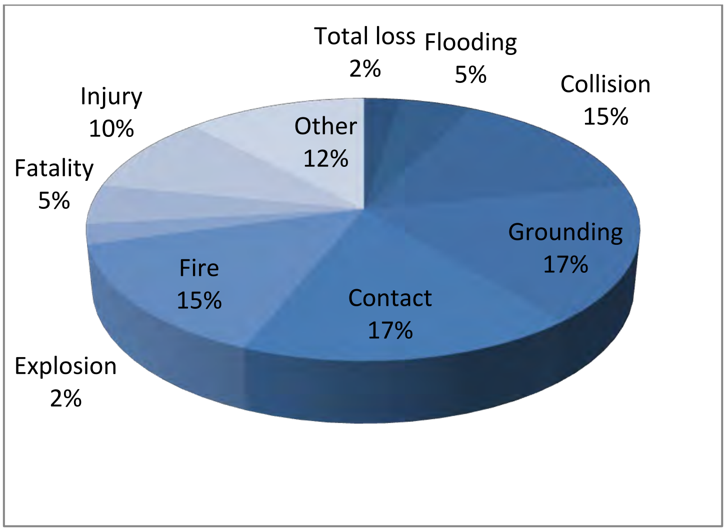

Figure 2 Ro-Ro vessels accidents consequences in the last decade

Source: Authors

Almost equal effect of inadequate procedures and policies, human factor and technical factor lead to 95% of Ro-Ro vessels accidents, and only 5% of accidents were caused by external factors (Figure 3).

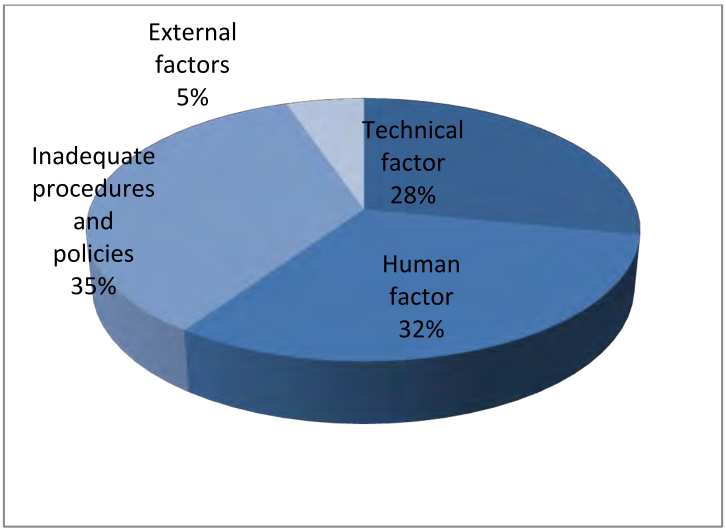

Figure 3 Ro-Ro vessels accidents causes in the last decade

Source: Authors

Bulk carriers were involved in 14 maritime accidents during last decade. Most frequent consequences of bulk carrier accidents were collision, grounding and fatality. These three consequences make 69% of all bulk carrier accidents in the last decade (Figure 4).

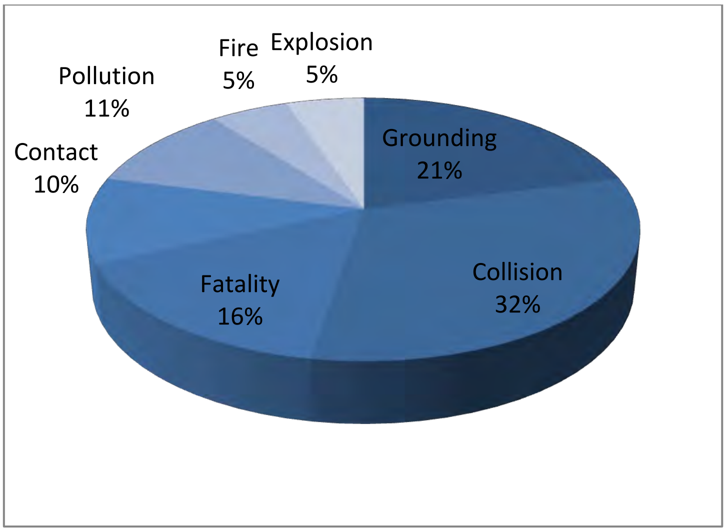

Figure 4 Bulk carriers accidents consequences in the last decade

Source: Authors

As it can be seen from Figure 5, human factor is main cause of bulk carrier accidents, closely followed by inadequate procedures and policies. Only small part of accidents was considered to be caused by external factors (4%).

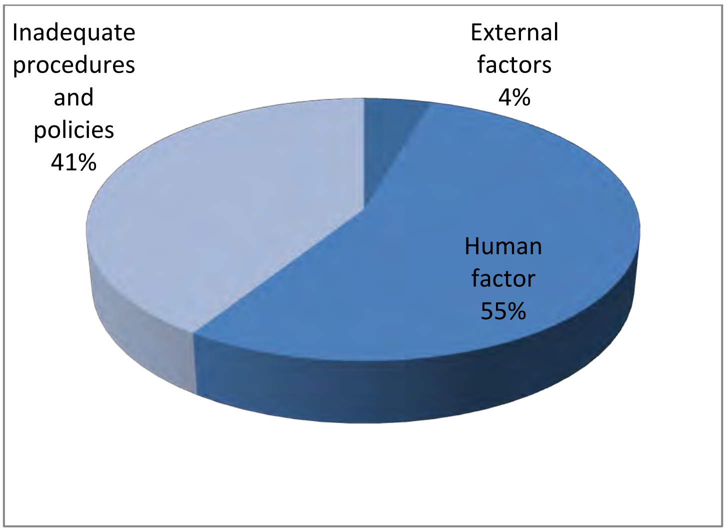

Figure 5 Bulk carriers accident causes in the last decade

Source: Authors

Tanker vessels (Oil tanker, Chemical/Product tanker, LNG, LPG) were involved in 17 accidents during analysed period. Most frequent accident types were collision (33%) followed by grounding (17%) and contact (17%) (Figure 6). Those three types of accidents make 67% of all tanker accidents.

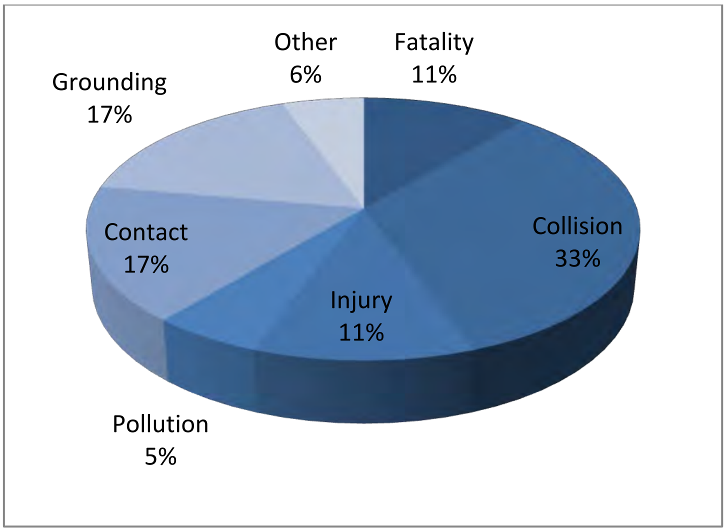

Figure 6 Tankers accidents consequences in the last decade

Source: Authors

According to tanker vessel accidents data analysis human factor contributed and caused 50% of accidents, inadequate procedures and policies 38% and technical factor 12%. Human factor and inadequate procedures and policies are factors that make substantial majority of tanker accidents causes in the last decade (Figure 7).

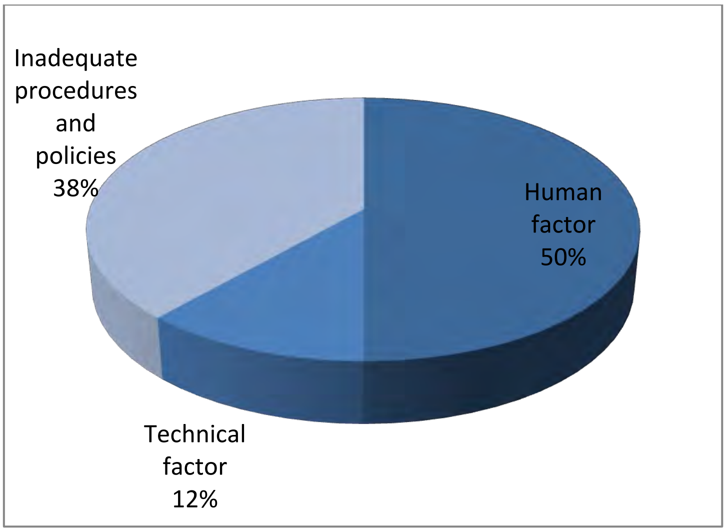

Figure 7 Tankers accidents causes in the last decade

Source: Authors

Container vessels were involved in 26 accidents in the last decade as per MAIB database. Fatality was the most represented type of accident, closely followed by collision and grounding (Figure 8).

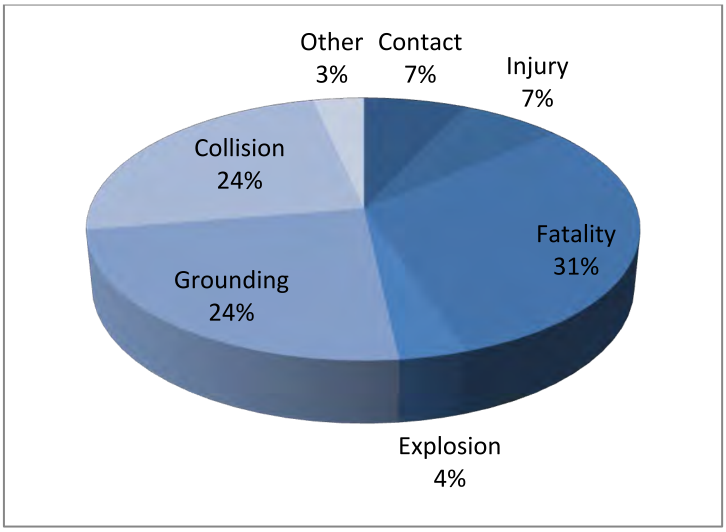

Figure 8 Container vessels accidents consequences in the last decade

Source: Authors

Human factor was most represented cause of container vessels accidents, followed by inadequate procedures and policies (Figure 9). Minor parts of accidents were caused by technical factor and external factor (14%).

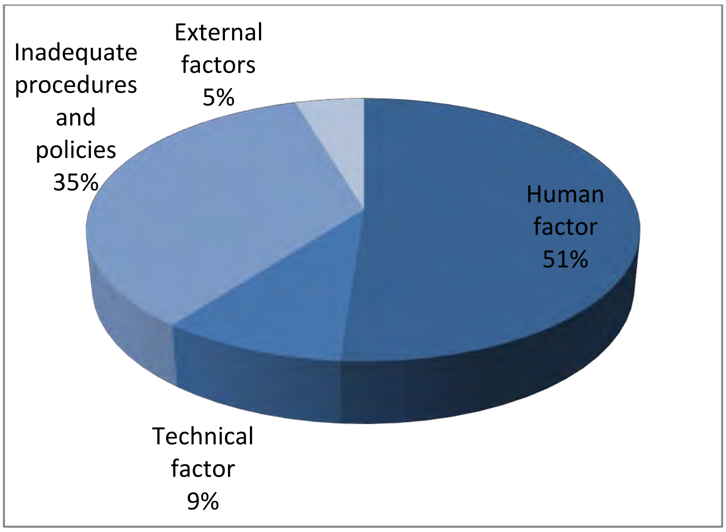

Figure 9 Container vessels accidents causes in the last decade

Source: Authors

General cargo vessels were involved in 32 accidents as per MAIB database. Grounding was most frequent type of accident, followed by fatality and collision (Figure 10). These three types of accidents make 65% of all general cargo accidents.

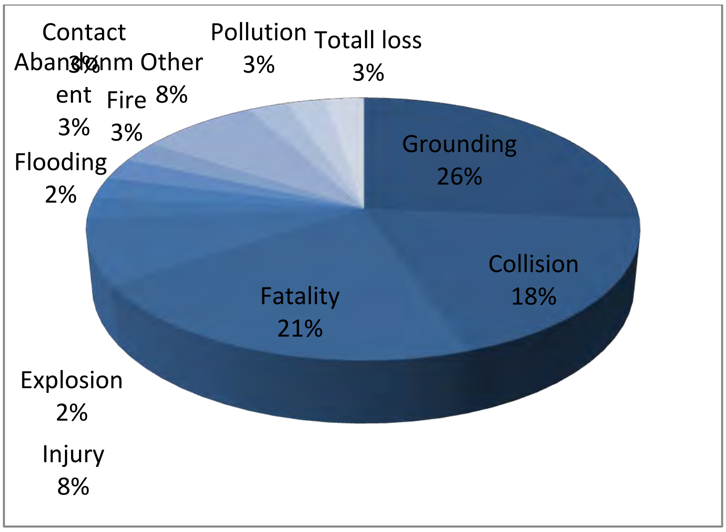

Figure 10 General cargo vessels accidents consequences in the last decade

Source: Authors

Human factor and inadequate procedures and policies make 79% of all causes of general cargo vessels accidents, technical factor and external causes make 19% and remaining 2% of causes are unknown factors (Figure 11).

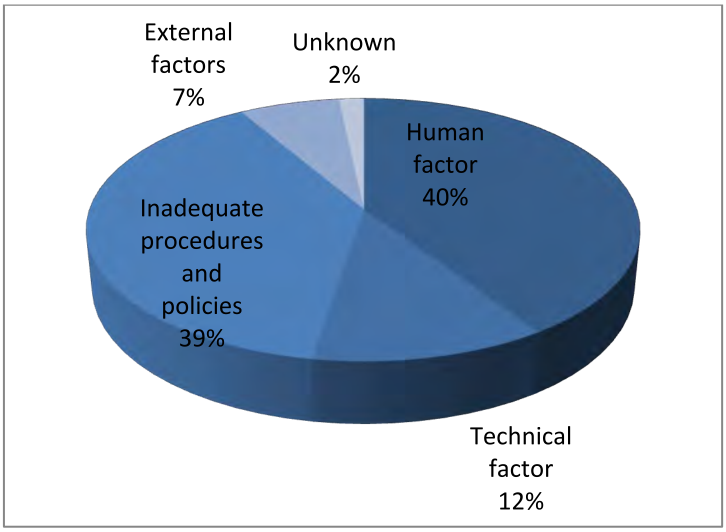

Figure 11 General cargo vessels accidents causes in the last decade

Source: Authors

Table 1 presents types of accidents according to type of vessel in the last decade.

Table 1 Vessel accidents according to accident type

	Type of accident					
Type of vessel	Grounding	Collision/ contact	Injury/ fatality	Fire/ explosion	Flooding/ sinking	Other
Ro-Ro vessel	7	13	6	7	3	5
Bulk carrier	4	8	3	2	0	2
Tanker vessel	3	9	4	0	0	2
Container vessel	7	9	11	1	0	1
General cargo vessel	10	8	11	2	1	6
Total	31	47	35	12	4	16

Source: Authors

As per analysed MAIB accident reports most endangered types of vessels are general cargo vessels and Ro-Ro vessels, and most frequent types of accidents were collision/contact, injury/fatality and grounding. Human factor is most frequent cause of marine accident, closely followed by inadequate procedures and policies. In order to determine trends for analysed types of vessels accident data is compared with previous studies.

4. DISCUSSION

According to study conducted by Eleftheria et al. (2016), Ro-Ro vessels exhibited highest accident frequency [10]. Previous study concerning safety of Ro-Ro vessels showed that the most common consequences of Ro-Ro accidents were: collisions (24%); machinery damage (17%): grounding (17%); shift of cargo and operational (16%); fire and explosion (14%) [10]. Another study on Ro-Ro vessels safety showed that collision/contact (33%), grounding (18%), injury/fatality (16%) and fire/explosion (9%) were most dominant types of accidents [9]. Since percentage of Ro-Ro vessels accidents types remains almost unchanged, measures introduced in order to eliminate and reduce Ro-Ro vessels accidents are inadequate and not fruitful. Another inauspicious fact is increase in percentage of fires and explosions. New technologies built in vehicles transported with Ro-Ro vessels increase risk of fire/explosion and all stakeholders involved in Ro-Ro transport should be aware of that and introduce measures that mitigate risk and improve overall safety of shipping [11].

In a study that conducted statistical analysis of ships accidents occurred in the period 1990-2012 it was observed that bulk carriers exhibited increased frequencies of collisions, hull/machinery damages, groundings and contacts [12]. According to same study, bulk carriers took fourth place in number of fatalities per ship type, after Ro-Ro vessels, general cargo vessels and passenger vessels [12]. Measures implemented in order to increase safety of bulk carriers managed to reduce number of contacts and hull/machinery damages, but number of collisions, groundings and fatalities is still relatively high. According to MAIB data from last decade, bulk carriers are safest vessels from analysed group.

As per previous studies, tanker ships showed increased frequencies for hull/machinery damage, collisions, groundings and contacts [12]. Analysis of MAIB database tanker accidents in the last decade showed that collision, grounding and contact were most frequent consequences of accidents, so measures introduced managed to reduce tankers hull/machinery damage. According to Eleftheria et al. (2016) lower frequency of serious accidents is observed for tankers [10].

Previous study observed that container vessels have high value for collision frequency [10], and another one included contacts and groundings [13]. As per MAIB accident reports from the last decade, fatality was the most frequent type of accident, followed by collision and grounding, what means that there is increase in fatalities on container vessels, since in previous studies there was a medium risk of fatality [10].

General cargo vessels were found to be most endangered types of vessels, since they were involved in most of the accidents in the last decade, according to MAIB database analysis. Previous studies showed that general cargo vessels exhibited increased frequencies with respect to collision, hull/machinery damage, grounding and contact [13]. High risk of fatality is also observed in one previous study, whereas 22% of total fatalities on all types of ships were assigned to general cargo vessels [10]. This analysis confirmed previous results and showed that there was no significant reduction in "typical" types of general cargo vessels accidents.

5. CONCLUSION

This article presents statistical analysis of recorded maritime accidents in the last decade and their consequences based on MAIB database. Human factor, inadequate procedures and policies are most common causes of maritime accidents and their common consequences are: collision/contact, injury/fatality and grounding. Most endangered type of vessels are general cargo vessels followed by Ro-Ro vessels.

When compared with previous studies it was found that consequences or types of accidents remain same. Conclusion drawn from that fact is that implemented corrective measures were not adequate and efficient. According to analysis, safety is still largely affected by human factor which is already identified by the International Maritime Organization (IMO). Specialized trainings were adopted by STCW 2010 to minimize accidents caused by human factor. Besides STCW requirements, Member States should encourage their companies to conduct trainings and collect any information and data about accidents, incidents and near misses in order to prevent recurrence of such events.

Since human factor is commonly greatest cause of all maritime accidents, all marine industry stakeholders should take efforts to minimize it and increase maritime safety through enhanced crewmembers training strategies, familiarisation with modern technologies and improving teamwork onboard vessels. Human factor should be thoroughly researched in order to mitigate risk of maritime accidents and globally improve maritime traffic.

Unfortunately, regulations change and introduction of new safety measures is always preceded by catastrophic accidents that usually have multiple fatalities as consequences. That needs to be changed by proactive thinking and implementing safety measures before accident occurs.

REFERENCES

[1] GuedesSoares, C.; Teixeira, A. P., "Risk assessment in maritime transportation," *Reliability Engineering and System Safety*, vol. 74, pp. 299-309, 2001.

[2] Samuelidis, M. S.; Ventikos, N. P.; Gemelos, I. C, "Survey on grounding incidents: Statistical analysis and risk assessment," Ships and offshore Structures, vol. 4, no. 1, pp. 55-68, 2009.

[3] Baniela, S. I.; Rios, J. V., "Maritime Safety Standards and the Seriousness of Shipping Accidents," The Journal of Navigation, vol. 64, pp. 495-520, 2011.

[4] International Maritime Organization, "Adoption of the Code of the International Standards and Recommended Practices for a Safety Investigation into a Marine Casualty or Marine Incident (Casualty Investigation Code)," IMO, Resolution MSC.255(84) 2008.

[5] International Maritime Organization, "Casualty - related matters; Reports on marine casualties and incidents," IMO, MSC-MEPC.3/Circ.3 2008.

[6] Baker, C.; McCafferty, D., "Accident database review of human element concerns: What do the results mean for classification?," in Proc. Int. Conf. Human Factors in Ship Design and Operation; RINA, 2005.

[7] Bielić, T.; Hasanspahić, N.; Čulin, J., "Preventing marine accidents caused by techonology-induced human error," Multidisciplinary Scientific Journal of Maritime Research, vol. 31, pp. 33-37, 2017.

[8] Erol, S.; Basar, E., "The analysis of ship accident occurred in Turkish search and rescue area by using decision tree," Maritime Policy & Management, vol. 42, no. 4, pp. 377-388, 2015.

[9] Vujičić, S.; Hasanspahić, N.; Mišković, D., "Importance of Leadership Qualities on Board Ships with Emphasis on Crisis Situation", ATINERs Conference Paper Series TRA2018-2529, Athens Institute for Education and Research, 2018, pp 3-16.https://www.hnb.hr/temeljne-funkcije/monetarna-politika/tecajna-lista/tecajna-lista

[10] GOV.UK, Marine Accident Investigation Branch (MAIB) reports. Available online: https://www.gov.uk/maib-reports (accessed on 10 May 2019).

[11] Gundić, A.; Frančić, V., "Particularity of safety measures on board ships operating in the "Motorways of the Sea" service," Multidisciplinary Scientific Journal of Maritime Research, no. 28, pp. 70-79, 2014.

[12] Eleftheria, E.; Apostolos, P.; Markos, V., "Statistical analysis of ship accidents and review of safety level," Safety Science, vol. 85, pp. 282-292, 2016.

[13] International Maritime Organization (IMO), "IMO and ro-ro safety," International Maritime Organization, London, 1997.

[14] gCaptain. (2016, February) Ro-Ro Safety Compromised By Fires and Explosions. Available online:https://gcaptain.com/ro-ro-safety-compromised-by-fires-and-explosions/ (accessed on 05 July 2019)

[15] Papanikolaou, A.; Bitha, K.; Eliopoulou, E.; Ventikos, N. P., "Statistical analysis of ship accidents occurred in the period 1990-2012," in Maritime Technology and Engineering Conference, Lisbon, 2015.

STUDY OF ADDED MASSES AND DAMPING FACTORS FOR A TYPICAL CARGO SHIP FROM BLACK SEA

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UDK 629.543(262.5)

Summary

In a study of the seakeeping performance it is important to take into account the added mass because if the energy of the water mass moved by the ship's body is neglected, the results of the dynamic response of the ship will be higher than those encountered in the real conditions. In this study, the added mass and damping effect for a typical Cargo Ship from the Black Sea are analyzed and calculated for heave, pitch and roll oscillations. The analyzed vessel has the features of the most common type of ship encountered in the Black Sea area, established after an analysis of the main dimensions of cargo vessels present in this area. This work represents the first step to establish the seakeeping performance of the ship in the Black Sea conditions and the results will be used further to study the influence of climate changes on the Black Sea navigation.

Keywords: Sea keeping; Black Sea; added mass; damping effect

1. INTRODUCTION

Along with global climate change, the seakeeping performance of vessels are suffering, and it is therefore necessary to study the past wave climate with future projections to determine seakeeping performance on ships in relation to new environmental conditions. This study is very important because we can identify the areas where extreme phenomena can occur and thus we can adapt the seakeeping performance to the new conditions through different devices or avoiding these areas. Also, with the analysis of the wave environment, it is possible to make new routes adapted to the seakeeping conditions of the ships, and therefore the safety on board increases as the routes will be chosen as safe as possible. The need for a study in the Black Sea is due to the large number of ships sailing in this area and to the climate change that may affect shipping.

A study of the seakeeping performances must be carried out on any ship from the preliminary design stage and this study begins with the analyses on the areas in which the ship will operate. In order to assess the influence of climate change on Black Sea navigation, we must first identify the main types of ships sailing in this area, the environment, the problems that Black Sea ships are currently facing due to the changes in the wave climate and the future projections of the wave climate and how they will affect shipping in this area.

This paper represents the first step in solving such a problem and deals with identifying the main types of ships present in the Black Sea Basin, selecting a ship from this set that can represent most of them, and starting a seakeeping study by identifying the damping coefficient and additional mass in the Black Sea conditions and the results will be used further to study the influence of climate changes on the Black Sea navigation.

The added mass effect is a factor that influences the movement of the ship in calm water, of which value varies with the frequency of the movement. As a result of water disturbance, made by the movements of the ship, the added mass phenomenon occurs and so the moments of inertia of the ship increase. The roll effect can increase by 5% and the vertical movement can increase by 50% [1]. Motion damping is another factor that influences the movement of the ship in calm water. This damping is the energy absorbed in an attempt to reduce the resistivity given by the viscous fluid to the vessel's movements [2]. The results obtained will be used to determine the RAO movements (operator response amplitude). RAO results can be obtained by calculations or experimental in the basin for prototype vessels, and if the vessel is already constructed, these results will be obtained in sea trials and are important for determining seakeeping performance and assessing calculations made by the naval architects [3]. This report has an important role both in presenting the results of regular movements in non-dimensional form and in presenting the results in the global motion in irregular waves [4].

There are also recommendations and steps to be taken to determine the ship's dynamic response in waves and can be found in the rules of classification societies [5], and also in various studies accessible to naval architects [6, 7].

2. TARGET AREA

The Black Sea is surrounded by Europe, Central Asia, and the Middle East. The European Union has in the south-east two countries that are open to the Black Sea, Romania and Bulgaria as you can see in figure 1, and this conferee a strategic location for Europe. The Black Sea communicates with the Mediterranean Sea through the Bosphorus Strait (Southwest Black Sea) and the maximum length between the eastern and western points is about 1175 km and its surface is 422000 km2, with a depth of approximately 2200 meters in the southern central area [8].

The Black Sea climate can generally be characterized as continental with pronounced variations in seasonal temperature, with climatic areas influenced by the shoreline. The northwest side of the basin is an area where we encounter cold winters and hot and dry summers, exposed to the northern air masses that create a cold winter current in the winter, and temperatures are decreasing considerably and form ice regularly [9].

Figure 1 Position of the Black Sea

Source: Google Earth

The Black Sea South-East is an area with a subtropical climate, abundant in precipitation, with warm winters and cold summers. The cold period of polar continental air is about 185 days a year and is accompanied by strong winds in the north-eastern area of the basin and frequent precipitation. The average temperature in January is 8 ° C in the central Black Sea region and decreases to 2 ° - 3 ° C in the western part of the Black Sea. The lowest temperatures were recorded in the Northwest of the basin at -30°C in winter and the highest during the summer in the Crimean region of 37°C. The wind makes its presence felt through the entire basin during the winter season, with severe tendencies in the north-west [9].

Navigation within the Black Sea Basin is generally conducted between shoreline countries through their main ports, such as: Romania with Constanta port, Bulgaria with Varna port, Russia with Novorossiysk harbor, Turkey with Trabzon, Samsun and Eregli, Ukraine with the port of Odessa, Georgia with the Batumi port, and communication with the outside of the sea is through the Bosphorus Strait. An analysis of the wind and wave climate along the shipping routes in the Black Sea was made by Rusu et al. [10]. The most important navigation routes in the Black Sea are defined between the ports mentioned above and these routes can be clearly seen in Figure 2 and Figure 3 in the density of ships between these ports. Also, there are no major changes between routes from one year to another, the navigation from years 2016 and 2017 presented in these graphs are almost identical. The main route at the Black Sea exit is the most crowded and leads to the Ocean through the Aegean Sea and the Mediterranean Sea. There are 50000 vessels crossing the Bosphorus Strait annually [11], and an important factor in the development of this number is the Russian port of Novorossiysk because here is reaching a large part of Central Asia's oil through pipelines and is loaded into oil tankers.

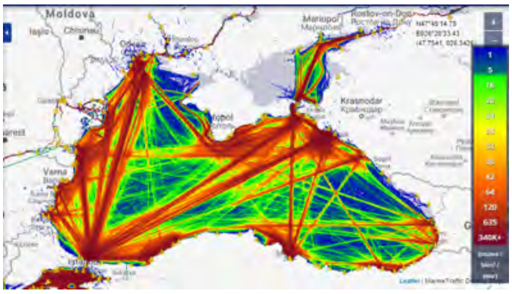


Figure 2 Density map of the navigation in the Black Sea in the year 2016

Source: https://www.marinetraffic.com

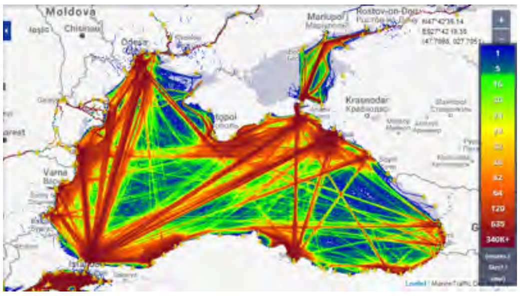


Figure 3 Density map of the navigation in the Black Sea in the year 2017

Source: https://www.marinetraffic.com

3. METHODOLOGY

3.1. Vessel interpolation

The main types of vessels which sail in the Black Sea are cargo ships, oil tankers, passenger ships, fishing vessels, Ro-Ro vessels, tugs, as shown in Figure 4.

Figure 4 Main types of vessels present in the Black Sea

Source: https://www.marinetraffic.com

From Figure 4, which centralizes all present ships in the Black Sea basin at date 08.06.2019, were selected vessels by category to identify the most relevant type of ship from the Black Sea, and these are shown in figures 5, 6, 7, 8, 9.

Figure 5 Cargo Vessels

Source: https://www.marinetraffic.com

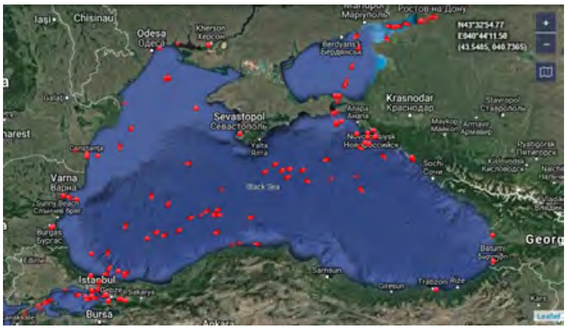


Figure 6 Tankers

Source: https://www.marinetraffic.com

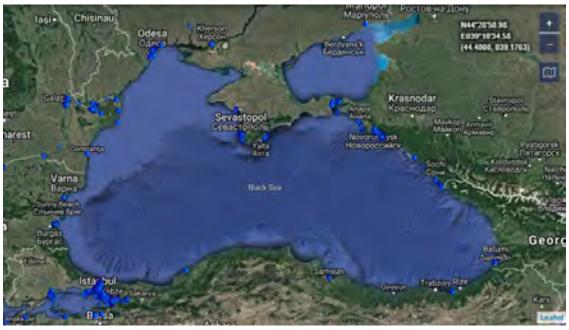


Figure 7 Passenger Vessels

Source: https://www.marinetraffic.com

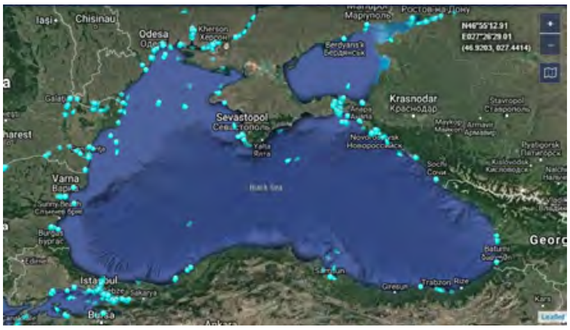


Figure 8 Tugs & Special Craft

Source: https://www.marinetraffic.com

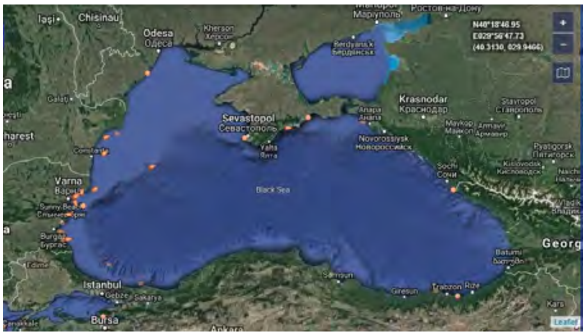
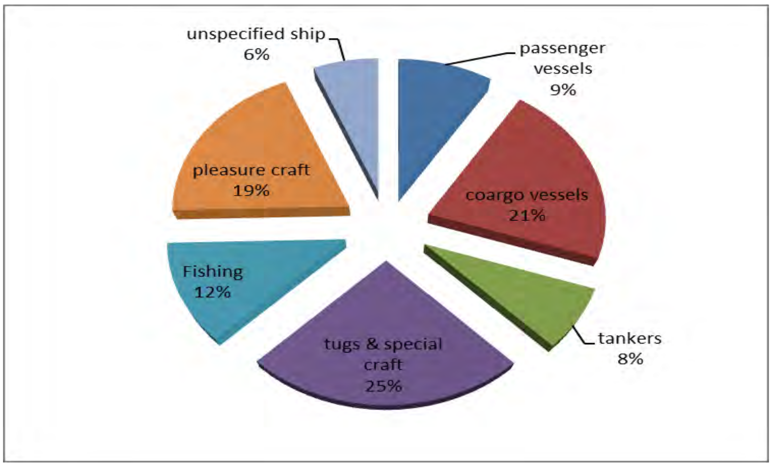


Figure 9 Fishing Vessels

Source: https://www.marinetraffic.com

According to data provided by the webpage marinetrafic.com [12], in the studies made on months May-June 2019 there is a trend that maintains the number of ships present inside the Black Sea from 7500 to 8500 vessels. This trend is also maintained as a percentage of the types of ships shown in chart no.1, which represents the data accumulated on day 08.06.2019 and comparable to other days is very similar, the only visible change is at passenger ships, to which we will have a higher percentage on weekends.



Graph 1 Vessels type present in the Black Sea at date 08.06.2019

Source: Original

On date 08.06.2019 there were 8561 ships in the basin of the Black Sea, of which the main category is represented by tugs and craft with 2105 vessels(24.59%), followed by cargo ships with a number of 1791 vessels(20.92%), as presented in Graph 1. Another important sector of this graphic is occupied by pleasure craft, 1628 ships (19.02%). Also, fishing vessels occupy 11.84% with 1014 vessels, 7.39% Tankers with 633 vessels, 8.82% passenger ships with 755 vessels, which number will decrease during the week days versus weekends, knowing that 08.06.2019 was Saturday. A percentage of 6.05% is represented by unspecified ship, 518 vessels.

In this paper the analyse was carried out on the cargo ships because by comparison to tugs and special craft or other categories of ships, they have routes in most of the black sea basin while the rest of the ships occupies the coastal area. Only tankers have similar routes, but due to the small number of ships in this category, it has been chosen to treat the cargo vessels. Also, tugs and special craft vessels have different shapes and sizes, making it very difficult to establish a ship-like pattern representing the entire sector, which is divided into self-propelled barges, tugs, catamarans, offshore technical vessels, etc. but because it represents an important percentage from all ships presented in the Black Sea, tugs and special craft will be analysed in future studies.

From the total number of 1791 cargo vessels, 500 were randomly selected and a study was carried out on the main characteristics of them, namely the length, width, and the draught. After studying the main dimensions, a ship with the most common dimensions was chosen and it supposed to represent a big part of the entire category of cargo ships.

3.2. Theoretical model

Numerical implementation of computational procedures can be done in the general case using common programming languages like Matlab, Visual Basic, C, FORTRAN, Pascal, or with some simplification assumptions in the form of table's calculations in Microsoft Excel which is used in this paper

Due to the general analyse of the type of the cargo vessels, we consider the simplified vessel shape plan with vertical edges, floating parameterized using Van der Fleet's relationship[3], symmetrical with respect to the diametral plane and middle ship. The mass distribution over the length of the ship shall be considered to be symmetrical in relation to the middle ship. The vessel has the longitudinal alignment with a trim equal to 0.

The following input data are considered:

L = length between perpendiculars [m]
B = maximum width [m]
d = average draft [m]
c_B = block coefficient
C_W= waterline coefficient
C_T= cross-section coefficient
A_{WL}= floating area
D = construction height [m]
x_F= waterline centre abscises
b(x) = hull centre abscises
ρ = 1.025 [t / m3] sea water density
g = 9.81 [m / s2] gravitational acceleration
n = 20 number of elements per length; δx = L/n [m]
ω = 0 - 2 [rad / s], δω = 0.05 [rad / s] wave frequency
u_s = cruising speed of the ship
Δ = ship displacement [t]
V = theoretical volume

$$\Delta = \rho c_B LBd = \rho\, A_{WL} d = \rho\, C_W LBd \rightarrow C_W = C_B \qquad (1)$$

$$c_T(x) = 1 \ \forall x \in [-\frac{L}{2}, \frac{L}{2}] \qquad (2)$$

$$b(x) = B\left[1 - \left|\frac{2x}{L}\right|^{\alpha}\right] \qquad (3)$$

$$A_{WL} = \int_{-L/2}^{L/2} b(x)dx = 2\int_{0}^{L/2} b(x)dx = LB\int_0^1 (1-t^{\alpha})dt = LB\left(1 - \frac{1}{\alpha+1}\right) \Rightarrow \alpha = \frac{c_W}{1-c_W} \qquad (4)$$

$$\int_{-L/2}^{L/2} x \cdot b(x)dx = 0 \Rightarrow x_F = 0 \qquad (5)$$

$$V = A_{WL} \cdot d \qquad (6)$$

3.2.1. Determination of added masses and hydrodynamic damping factors

The encounter vessel-wave frequency has the expressions:

$$\omega_e = \omega - k \cdot u_s \cos\mu \qquad k = \omega^2/g \qquad u_s = 0 \Rightarrow \omega_e = \omega \qquad (7)$$

The body of the ship may be considered elongated if the length ratio with width L / B = 5 ÷ 7 and the relation of added mass for this assumption is:

$$M_{jk} = \int_{-L/2}^{L/2} m_{jk} dx \;\; ; \;\; m_{jk} = -\rho \int_C \phi_k \frac{\partial \phi_j}{\partial n} dl \;\; ; \;\; j,k = 1,6 \tag{8}$$

Where M_{jk} represents the additional mass on the degree of freedom j in the movement on degree k of freedom and m_{jk} = 1, 6(1 to 3 are translations; 4 to 6 are rotations) represents the additional mass per unit length of the ship corresponding to the section x coordination.

The hydrodynamics damping force on the degree of freedom j in the movement on the degree of freedom k can be written as:

$$F_{jk} = B_{jk} \cdot v_k \;\; ; \;\; B_{jk} = \int_{-L/2}^{L/2} N_{jk} dx \;\; ; \;\; j,k = 1,6 \tag{9}$$

where Bjk is the hydrodynamic damping factor, respectively Njk is the hydrodynamic damping coefficient per unit length of the ship.

The added masses and the hydrodynamic damping factors per unit of length at the oscillations: vertical (33), pitch (55) and roll (44) are determined with the relations [13]:

$$m_{33}(x,\omega) = c_{33}(x,\omega) \cdot \frac{\rho \pi b^2(x)}{8} \qquad m_{55}(x,\omega) = x^2 \cdot m_{33}(x,\omega) \qquad m_{44}(x,\omega) = c_{44}(x,\omega) \cdot \rho \pi d^4 \tag{10}$$

$$N_{33}(x,\omega) = \lambda_{33}(x,\omega) \cdot \frac{\rho \omega b^2(x)}{4} \qquad N_{55}(x,\omega) = x^2 \cdot N_{33}(x,\omega) \qquad N_{44}(x,\omega) = \lambda_{44}(x,\omega) \cdot \rho \omega d^4 \tag{11}$$

The non-linear hydrodynamic coefficients of oscillation are calculated for the shape of the ship with the Lewis form (the contour of a transversal ship section is turned into a circle with a unitary radius) and are functions of the following parameters: c33, c44, λ33, λ44 = f(c_T, H, δ);

Additional masses and hydrodynamic damping factors for the ship's body are:

$$M_j(\omega) = \int_{-L/2}^{L/2} m_j(x,\omega) dx = 2\delta x \sum_{i=11}^{20} m_{ji}(\omega) \tag{12}$$

$$B_j(\omega) = \int_{-L/2}^{L/2} N_j(x,\omega) dx = 2\delta x \sum_{i=11}^{20} N_{ji}(\omega) \tag{13}$$

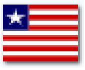
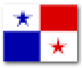
where j ∈ {33, 44, 55}

The method presented above for added mass study was proposed by Lewis [13] and is valid on the vibration range (ω → ∞), when they have a poor dependence on the frequency of the movement.

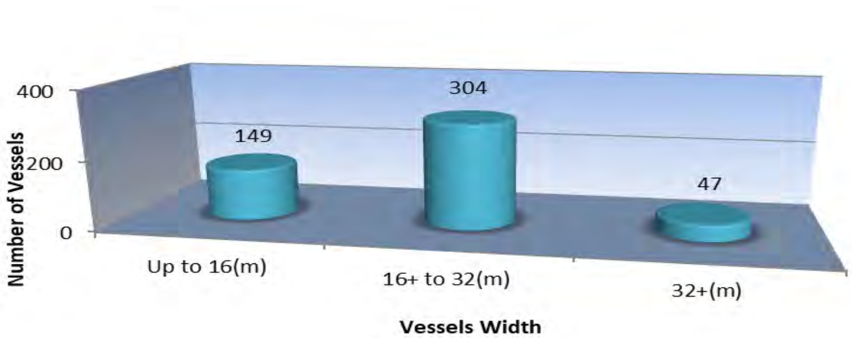
4. RESULTS & DISCUSSION

The present study examines the main types of ships that sail in the Black Sea and the beginning of the seakeeping study of the most common ships in this area. The type of ship treated in this paper is a cargo ship and this type of ship is chosen because it is a ship that is very common in Black Sea waters. On 08.06.2019 there were 1791 cargo ships in the Black Sea and the analysis was made on a number of 500 randomly chosen vessels. Table 1 lists a small part of the analysed vessels.

Table 1 Example of analyses Cargo Ships from the Black Sea

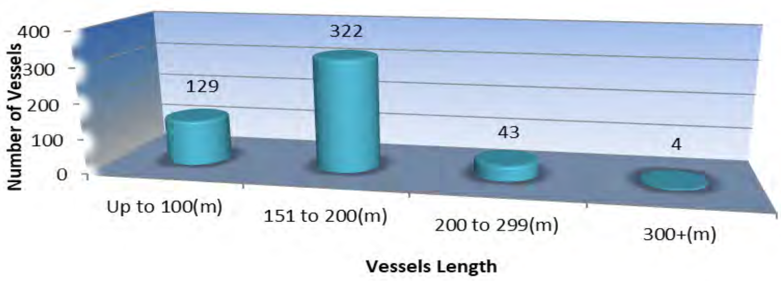
Flag	Vessel Name	Length	Width	Draught	Photos	Reported Destination	Current Port
	SEA POWER	91.8m	21.6m	3.8m		GRENAA	YALOVA
	MSC AUGUSTA	187.4m	28.4m	6.7m		VARNA	-
	NATALI	90.8m	13.5m	4.8m		KHERSON	-
	ROZA A	168.8m	27.3m	7.9m		GRPIR	-

Since the analysis of the added mass and the damping factor is made by simplifying assumptions, such as symmetry with the diametral plane and the middle ship, on these 500 vessels were analyzed only the main dimensions of the ship, making a cooperation between these to observe the predominant type of ship, and the results are presented as follows: Figure 2 shows the number of ships with a width between 0-16 meters; 16-32 meters and 32 meters and higher. In Chart 3 the lengths of the ships are represented and in Chart 4 the ship draught.



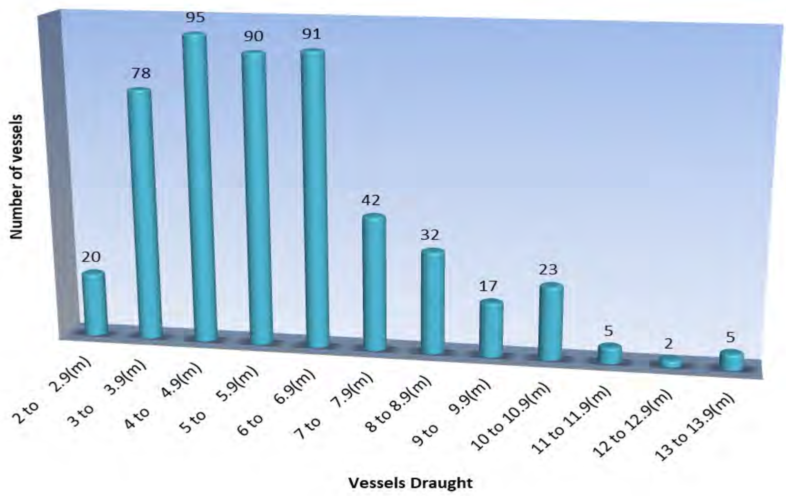
Graph 2 Trend of Vessels widths in Black Sea

Source: Original



Graph 3 Trend of Vessels lengths in the Black Sea

Source: Original



Graph 4 Trend of Vessels draughts in the Black Sea

Source: Original

As can be seen in Graph 2 in which ship lengths are presented, from the studied vessels the most numerous are between 16 and 32 meters, with a total of 304 ships out of a total of 500. From the 3rd graph results that 322 ships are in the ship's length range of 151 meters to 200 meters and in Graph 4 are shown that in the Black Sea ships are sailing with a draft between 3 and 7 meters.

Knowing the data of these charts, a ship was randomly selected to meet the predominant Black Sea cargo characteristics and thus resulted in a vessel of 179.9 meters length, 28.4 meters wide and a draft of 6 meters at the time when the analysis was done, with the possibility to have a 10 meters draft at full load. The ship is presented in Figure 10

Figure 10 Analysed Vessel

Source: https://www.marinetraffic.com

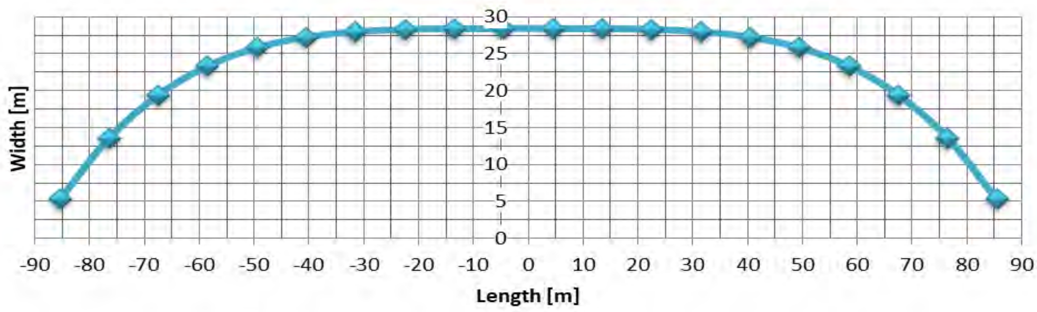
According to the known and calculated data from the tables 2 and 3, and the simplifications made, the shape of the ship resulted and is presented in figure 5 and the shape is given by the section centre abscises (20 sections) along the length of the ship.

Table 2 Main characteristics of the vessel

L	179.9	m	V	38318.7	m3	Iy	7942243	m4
B	28.4	m	cw=cB	0.750		R	207.2681	m
d	10	m	D	39276.67	t	Ix	225398.5	m4
cB	0.750	[3]	n	20		r	5.882206	m
h0	3.7988725		dx	8.995	m	zB	5	m
us	0	m/s	Jy	79446904	tm2	zG	7.083333	m
ρ	1.025	t/m3	Aw	3831.87	m2	a	2.083333	m
g	9.81	m/s2	Jx	3959874	tm2			

Table 3 centre abscises of section hull

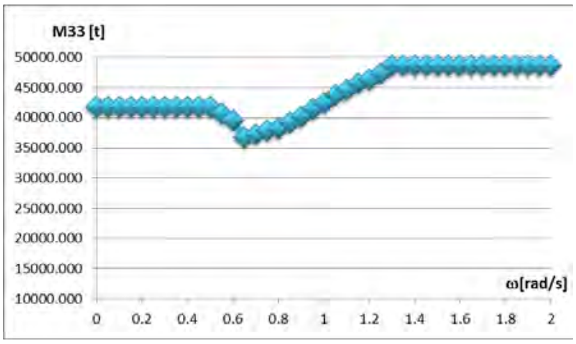
NrC	i	xi	bi	NrC	i	xi	bi
0.5	1	-85.4525	5.268023	10.5	11	4.4975	28.39982
1.5	2	-76.4575	13.57502	11.5	12	13.4925	28.38562
2.5	3	-67.4625	19.41406	12.5	13	22.4875	28.28906
3.5	4	-58.4675	23.33042	13.5	14	31.4825	27.97382
4.5	5	-49.4725	25.80122	14.5	15	40.4775	27.23542
5.5	6	-40.4775	27.23542	15.5	16	49.4725	25.80122
6.5	7	-31.4825	27.97382	16.5	17	58.4675	23.33042
7.5	8	-22.4875	28.28906	17.5	18	67.4625	19.41406
8.5	9	-13.4925	28.38562	18.5	19	76.4575	13.57502
9.5	10	-4.4975	28.39982	19.5	20	85.4525	5.268022



Graph 5 Centre abscises of section hull (20 sections)

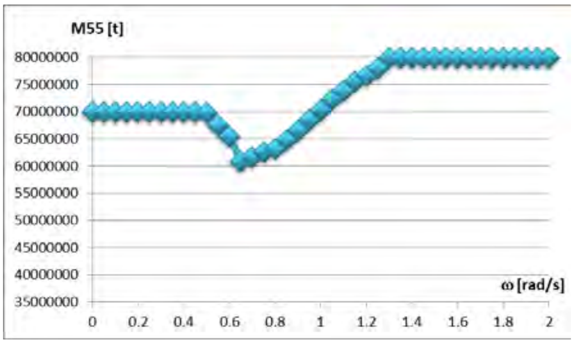
Source: Original

Based on the method presented in chapter 3.2, we calculated the non-dimensional coefficients for the added mass c33, c44 and the hydrodynamic damping coefficient λ33, λ44 at the degree of freedom 3 vertical displacement, and 4 the displacement around the x-axis (roll) approximated by multiparametric conformational transformation with n = 1. The spectral results include the oscillation field as well as the vibration field. The calculation of these coefficients was made for each strip, the ship being divided into 20 strips and in graphics 6, 7, 8, 9, 10, 11 the final results of the added mass and the hydrodynamic damping coefficient for the vertical, pitch and roll movement are presented.



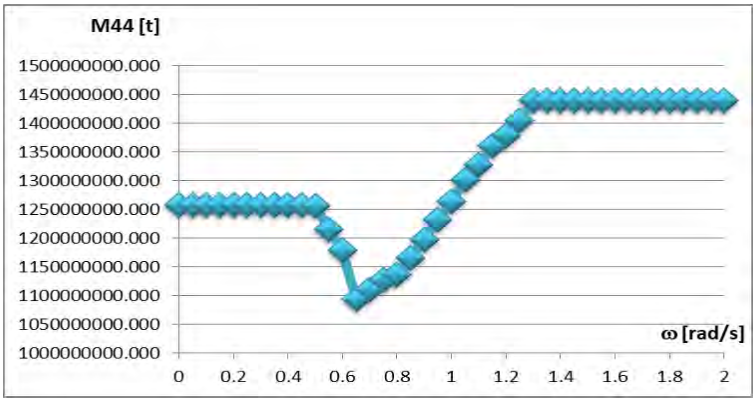
Graph 6 Heave added mass

Source: Original



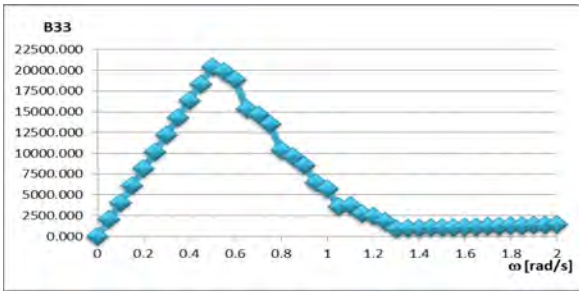
Graph 7 Pitch added mass

Source: Original



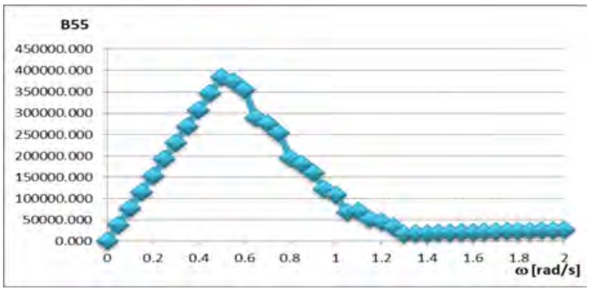
Graph 5 Rolling added mass

Source: Original



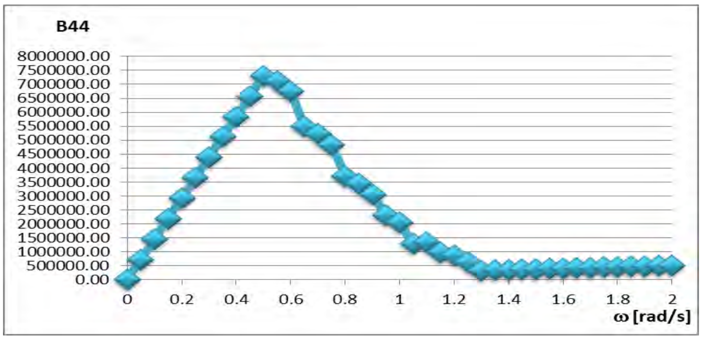
Graph 8 Heave damping coefficient

Source: Original



Graph 9 Pitch damping coefficient

Source: Original



Graph 10 Rolling damping coefficient

Source: Original

As can be seen in these resulted graphs, the addition and damping factor is much higher at the rolling movements than the pitch and the heave movements.

Given the simplifications made for this calculation, where we considered c_T being equal to 1 and the symmetry of the fore with the aft from in correspondence to middle ship, it resulted in a ship with large flat surface which led to the hydrodynamic added mass associated with the sinking body to be much larger than the mass of the ship. This type of study can be applied to vessels with high block coefficients, in which ship shapes are similar to geometry resulting from simplifications made, and as types of ships that can be included in these types of study are cargo ships and tankers.

These results represent only the first step of the seakeeping analysis for the selected ship, the future analyses will include the determination of its own pulses of the vessel oscillations, the determination of the transfer function to the oscillation on the vertical pitch and roll and the determination of the short and long term dynamic response of the ship's oscillations. Also, it is well known that the seakeeping performance of a vessel depends on the environmental conditions. Thus, the next step will be to evaluate the dynamic responses for the selected ship under the predicted sea states conditions provided by a wave model in the Black Sea basin (especially along the shipping routes). Future studies will be focused to evaluate these aspects, together with the analysis of the ship operability based on various seakeeping criteria (see for example the studies [14-16]. Long-term analyses of the sea state conditions in the Black Sea will be performed based on historical data (hindcast simulations), as those made by Parunov el al. in the Adriatic Sea [15]. The impact of climate changes can be evaluated by comparisons of the historical data with the projections of the future sea state conditions [16]. These comparisons will show us whether changes of the sea states conditions will occur along the most important shipping routes in the Black Sea and how will affect the seakeeping performance of the ships. The main dimensions of the ships that are in preliminary design phase can be modified to eliminate occurred problems if necessary, which will also lead to a change in the results of the additional mass and the damping coefficient, being directly correlated with the main dimensions of the ship. Furthermore, from an economic point of view, but also to protect the environment, great care should be taken at fuel consumption and at drag resistance of the ship.

5. CONCLUSIONS

This paper presents the beginning of the seakeeping study by calculating the added mass and the damping factor on a Cargo vessel, the vessel designed to represent a majority of this type of vessels present in the Black Sea basin, resulting from an analyse of 500 vessels encountered in this area.

The main types of ships encountered in the Black Sea at the time this study was made were tugs and crafts, followed by cargo ships. The tugs and crafts category is composed of several subcategories of ships that have different geometric characteristics and because of this we can't identify a ship-like pattern representing the entire sector and therefore the chosen category studied in this paper are cargo ships. This study can be applied at similar ships, with big block coefficient and hull form U, V.

According to this study higher values of the additional mass and the hydrodynamic coefficient of damping resulted in the rolling movements compared to the pitch movement and the heaving movement. It has also been found that the additional mass is greater than the mass of the vessel, which is encountered in vessels with elevated block coefficients, that has U,V hull forms, as is the case with the vessel studied.

It is necessary to include this type of study in seakeeping performance calculations, which calculates the added mass and the damping factor because they bring the final result to a value much closer to reality.

The results from this study will be used further to see the seakeeping performance. This study will be conducted on several types of vessels and the overall objective is to assess the influence of climate change on Black Sea navigation. The final results will identify and disseminate the problems that the Black Sea vessels are currently facing due to changes in the wave environment, but also the way in which future wave projections will affect shipping in Black Sea area.

ACKNOWLEDGMENT

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REFERENCES

[1] Tupper, E. C., Introduction to naval architecture, Fourth Edition, 2004, Chapter 11, pp. 223-224; Chapter 12, pp. 234-236
[2] Bhattacharya, R., *Dynamics of Marine Vehicles*, 1978
[3] Obreja, D., Manolache, L., Popescu, G., Bazele proiectării preliminare a navei (in Romanian), 2003
[4] The Maritime Engineering Reference Book A Guide to Ship Design, Construction and Operation 2008, Pages 483, 485-577
[5] Class guideline – DNVGL-CG-0130, Edition January 2018, Section 2 Wave Conditions, Ch. 2 Regular waves
[6] ITTC 2017, "Proceedings of 28th ITTC Vol I, The Seakeeping Committee Final report and Recommendations to 28th ITTC", UK] [ITTC 2005, "Proceedings of 24th ITTC Vol I, The Seakeeping Committee Final report and Recommendations to 24th ITTC", UK]
[7] ITTC 2008, "Proceedings of 25th ITTC Vol I, The Seakeeping Committee Final report and Recommendations to 25th ITTC", Fukuoka
[8] ecomareaneagra.wordpress.com/marea-neagra, accessed in June 2019
[9] Goncharov, V. P., Fomin, L. M., Kosarev, A. N., Black Sea, Encyclopaedia Britannica, 1999
[10] Rusu, L., Raileanu, A., Onea, F., *A comparative analysis of the wind and wave climate in the Black Sea along the shipping routes*, 2018, Water, Vol. 10. No 7, 924, DOI:10.3390/w10070924.
[11] Bosphorus Strait News Yearly Ship Statistics of Bosphorus Strait, http://www.bosphorusstrait.com/, accessed in June 2019
[12] marinetraffic.com, accessed in May and June 2019

[13] Domnisoru L., Ship dynamics. Oscillations and vibrations of the ship's body, 2001

[14] Gasparotti, C., Rusu, L., Prediction of the dynamic responses for two containerships operating in the Black Sea, 2014, *Journal of Naval Architecture and Marine Engineering* 11 (1), 55-68. http://dx.doi.org/10.3329/jname.v11i1.17289

[15] Rusu, L., Guedes Soares, C., Forecasting fishing vessel responses in coastal areas. 2014, *Journal of Marine Science and Technology* 19 (2), 215-227. http://dx.doi.org/10.1007/s00773-013-0241-2

[16] Rusu, L., Guedes Soares, C., Forecasting containership responses in the Azores Archipelago, 2014, *Developments in Maritime Transportation and Exploitation of Sea Resources* – Guedes Soares & López Peña (eds), Taylor & Francis Group, London, Vol 2, 987-993.

[17] Parunov, J., Ćorak, M., Pensa, M., Wave height statistics for seakeeping assessment of ships in the Adriatic Sea, 2011, *Ocean engineering*, *38* (11-12), 1323-1330.

[18] Rusu, L., Evaluation of the near future wave energy resources in the Black Sea under two climate scenarios. 2019, Renewable Energy 142, 137-146. https://doi.org/10.1016/j.renene.2019.04.092

MEASUREMENT AND CONTROL SYSTEM FOR A DIVER'S ROBOTIC LEG

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UDK 626.022:004

Summary

Although developing a swim-fin, which assures better performance of a diver during underwater activities, seems to be a challenging area, few researchers have addressed the problem of analysis and comparison of different models of swim-fins because of the need for designing an automatic solution to carry out experimentation with reliable results. Therefore, in order to facilitate comparison analyses, we have designed and developed the test bench, which enables carrying out experiments in flowing water. This paper reports the design of measurement and control system for a diver's robotic leg, which has been developed based on movement pattern obtained using computer vision techniques as well as qualitative analyses of robotic leg behaviour during initial experiments. Our solution can be applied for testing a wide range of motions and fins' types utilising movement parameters implemented in the control algorithm.

Keywords: robotic leg, control system, software architecture

1. INTRODUCTION

There is considerable interest in developing a swim-fin, which assures better performance of a diver during underwater activities. To achieve this goal, a lot of swim-fins, made of different materials and moulded in various shapes have been constructed [1]–[3], [6]. Due to the fact that a swim-fin commercial market is mostly devoted to entertainment, very few papers concerning design process have been published. Only a substantial number of patents has been proposed.

Another area where efficiency of a swim-fin plays an important role is biomimetic underwater vehicles technology [4], [5], [8]–[11]. This is connected with the fact that an efficient fin can increase the range of a vehicle, which may contribute to reducing its weight and size. Therefore, some research in recent years has focused on a swim-fin's shape and flexibility as well as its movement optimization. Numerous experiments have established that "fish-like" underwater vehicles, equipped with undulating propulsion, could be more efficient than propeller based ones [4], [12], [13],[14].

Although it is generally accepted that the efficiency of a swim-fin is vital in many applications, few researchers have addressed the problem of analysis and comparison of different models of swim-fins.

Additionally, some approaches evaluate swim-fin propulsion as a global system, where diver's physiological and biomechanical responses are considered [7]. However, reproducible swimming technique is difficult to obtain due to the diver's fatigue during an experiment. Therefore, an automatic solution is needed to carry out reliable tests.

The development of the automatic solution is time consuming and technically difficult, because in order to take into account a large number of determinants, the trial should be performed in flowing water. The test bench, based on moving device in a swimming pool has been proposed in [7]. In this attempt, the swim-fin is moved along the side of a swimming pool. Another concept, which is widely used during determination of underwater vehicle hydrodynamic coefficients, assumes that a vehicle is immobile, whereas water flows around it. Due to the fact that this solution simplifies construction of the test bench as well as facilitates test performance, it was employed in our work.

The purpose of this paper is to present elaborate measurement and control system for a diver's robotic leg. In the next section, the movement pattern of a diver's leg, established during preliminary research, is described. Then, the structure of the system as well as software architecture are presented. At the end, results and conclusions are discussed.

2. MOVEMENT PATTERN OF A DIVER'S LEG

A genuine pattern of movement of a diver's leg plays an important role in our research. Therefore, in order to obtain necessary data, the experiment with a diver was conducted in a swimming pool. The diver's leg was marked with yellow spots, which enabled us to trace its movement. For the purpose of obtaining representative data, the diver was moving his legs with different speeds using various types of fines. Ultimately, six from all recordings were taken into consideration. To analyse them, a computer vision algorithm was designed and implemented into a window application in C++ programming language with the use of OpenCV library (Fig. 1).

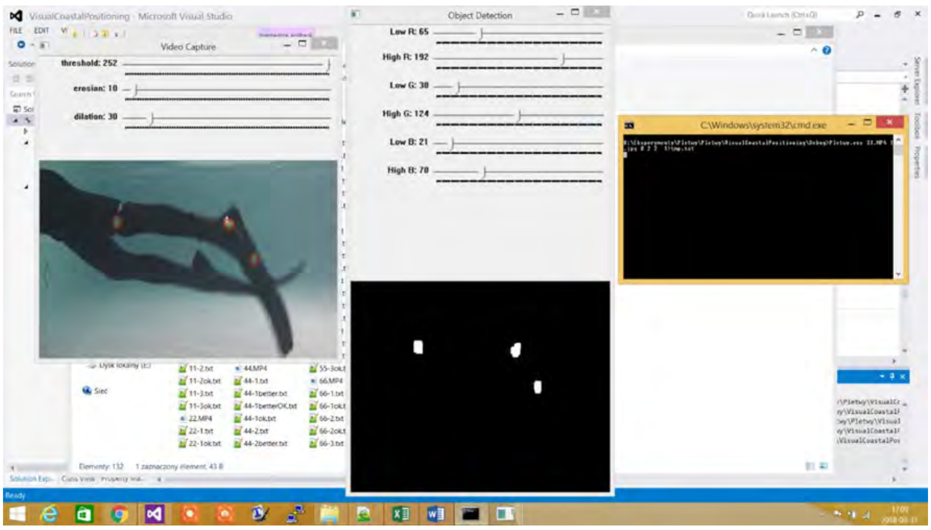

Figure 1 Graphical user interface of the computer application

The computer vision algorithm, as proposed in our previous work [10], can be divided into following parts:

- Conversion between RGB and HSV colour spaces.
- Extraction of yellow pixels representing markers.
- Thresholding.

- Erosion.
- Dilatation.
- Localisation of obtained blobs in the image.
- Elimination of the false blobs.
- Prediction of locations of the marker in the current image based on the previous image in case of not detecting the corresponding blob.

Preliminary experiments, conducted in a swimming pool in order to find the best method for detecting markers in underwater environments, has shown that HSV space facilitates better colour detection in the underwater environment than other colour spaces. Usage of this space allowed flawless detection of yellow markers in spite of changing light condition in the swimming pool. To localise the markers on the image, double thresholding with previously established parameters Min_{H,S,V}, Max_{H,S,V}, representing lower and upper threshold, was executed. Nevertheless, some random pixels, incorrectly classified as a marker area, still existed on the image. In view of this fact, morphological operations erosion and dilatation were utilized for removing them from the pictures.

Due to the fact that the likelihood of wrong detection still existed, additional processing, which considered comparison between actual and previous location of the markers, was executed. In this technique, if the position of the marker significantly differs from positions of all the detected blobs in the previous image, the marker is removed and its position is determined using a linear estimator.

The above algorithm allowed for tracking of the markers in a video stream. Additionally, in view of the fact that an image acquisition rate and all necessary dimensions of the observed scene were known, the following parameters for recorded movies were calculated:

- Pixel positions of the markers.
- Angles between the arms.
- Angular velocities of the arms.

Exemplary results, obtained with the developed algorithm, are presented below.

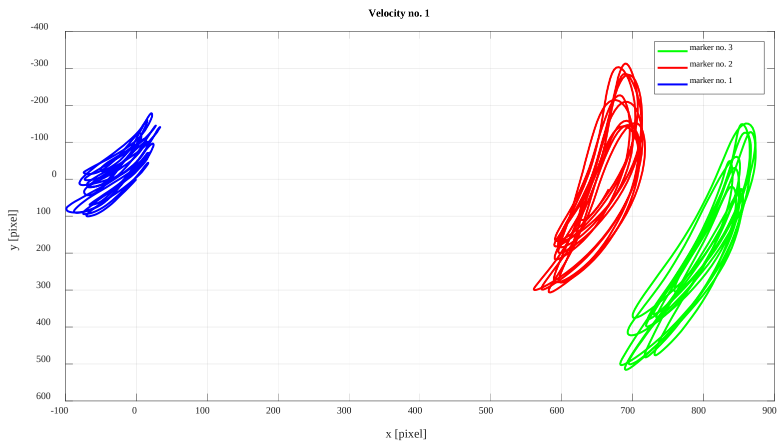

Figure 2 Markers' positions for velocity no. 1 (slow movement)

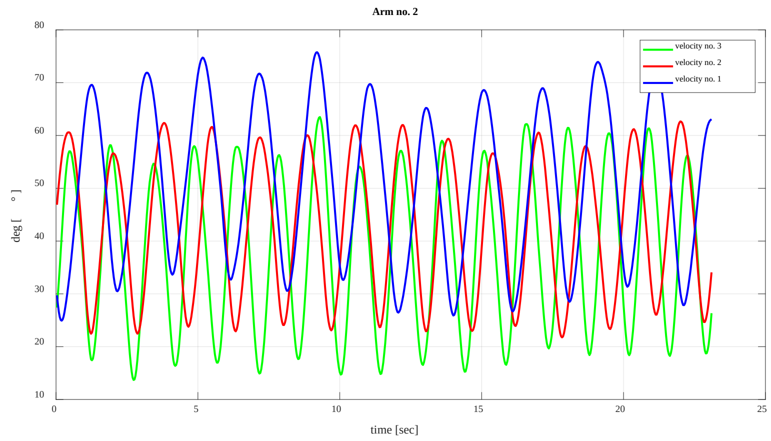

Figure 3 Arm no. 2 angular positon

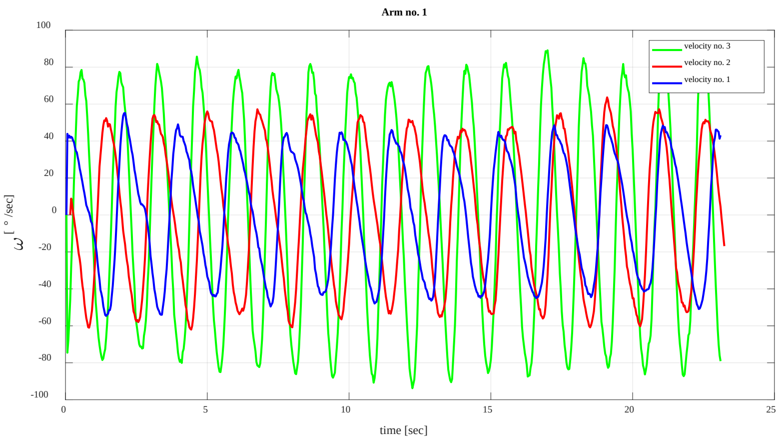

Figure 4 Arm no. 1 angular velocity

More detailed description of the developed algorithm and an extensive results' presentation and analysis can be found in [10].

3. DIVER'S ROBOTIC LEG

The diver's robotic leg, designed and developed in order to carry out presented research, is depicted in the figure below.

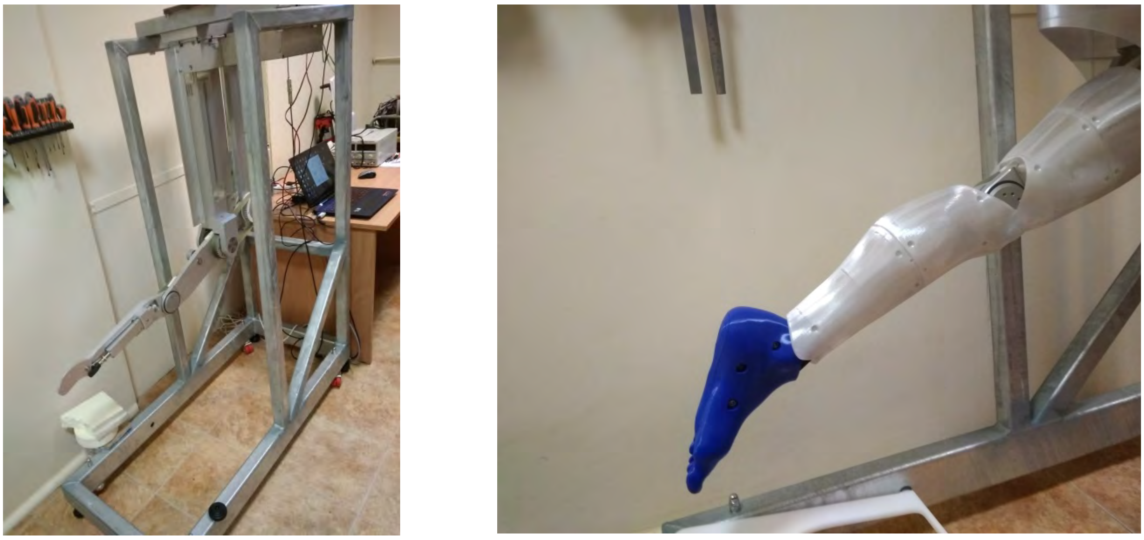

Figure 5 Diver's robotic leg

It consists of two arms, a calf and a thigh, propelled by two motors, and a foot. The foot's position is controlled by a piston attenuator. The piston attenuator is used with the intention of simplifying construction and better simulation of human animation. The motors are located in the upper side of the construction, whereas torque is transmitted through a system of gearboxes to a single articulated joint via V-belt. This construction allows to operate motors in the air, while joints are located underwater and lubricated with flowing water. Consequently, the structure is simplified and more reliable.

In order to operate the leg as well as carrying out necessary measurements, the control and measurement system presented in the Fig.6 has been developed.

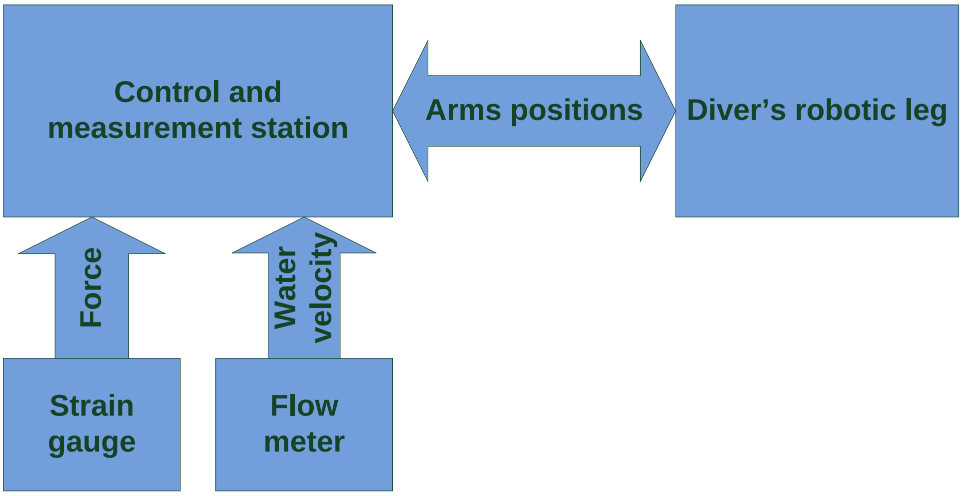

Figure 6 Control and measurement system

The control and measurement station determines leg's position and gathers necessary data. To change the leg's position, brushless DC motors supervised by the drive controllers mcDSA-E45 (Fig.7a), are used. The drive controller is connected to the control and measurement station using miCAN-Stick2 CAN/USB converter (Fig. 7b), which enables exchanging data between the station and the controller.

a) b)

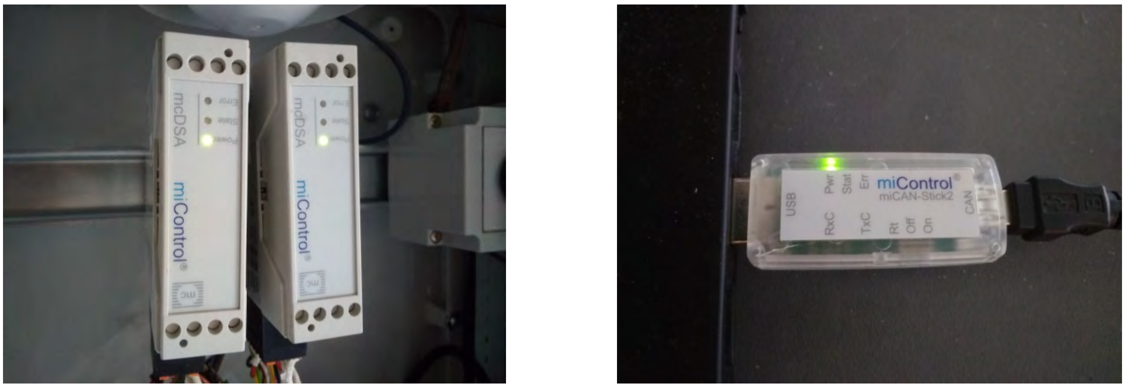

Figure 7 a) Drive controller mcDSA-45, b) miCAN-Stick2 converter

For the purpose of data collection, a strain gauge meter and a flow meter are used. The strain gauge meter measures thrust generated by the leg, utilising HBM PW4C3/300G-1 transducer depicted in figure below.

Figure 8 HBM PW4C3/300G-1 transducer (source: www.exalt.pl)

To work correctly, the transducer is required to be connected to an amplifier; in our work, 1-PAD4001A-RS4 amplifier with RS-485 interface is applied. As a result, RS-485 to USB converter is needed to enable data transfer between the station and the strain gauge.

In order to measure water flow, an ultrasonic liquid flow meter NFM300M.H was employed (Fig. 9).

Figure 9 NFM300M.H ultrasonic liquid flow meter (source: www.automatyka.pl)

Sensors of the flow meter were mounted around the water tunnel, while the transducer was connected to the station via Modbus (serial connection protocol). In this case, the RS-485 to USB converter is also used.

4. SOFTWARE ARCHITECTURE

A computer application, which was employed to control the robotic leg as well as to gather and record necessary data, was developed using C++ programming language and Qt libraries. The advantage of this solution is that it is independent from operational system and is equipped with a graphical user interface (GUI), presented in the figure below.

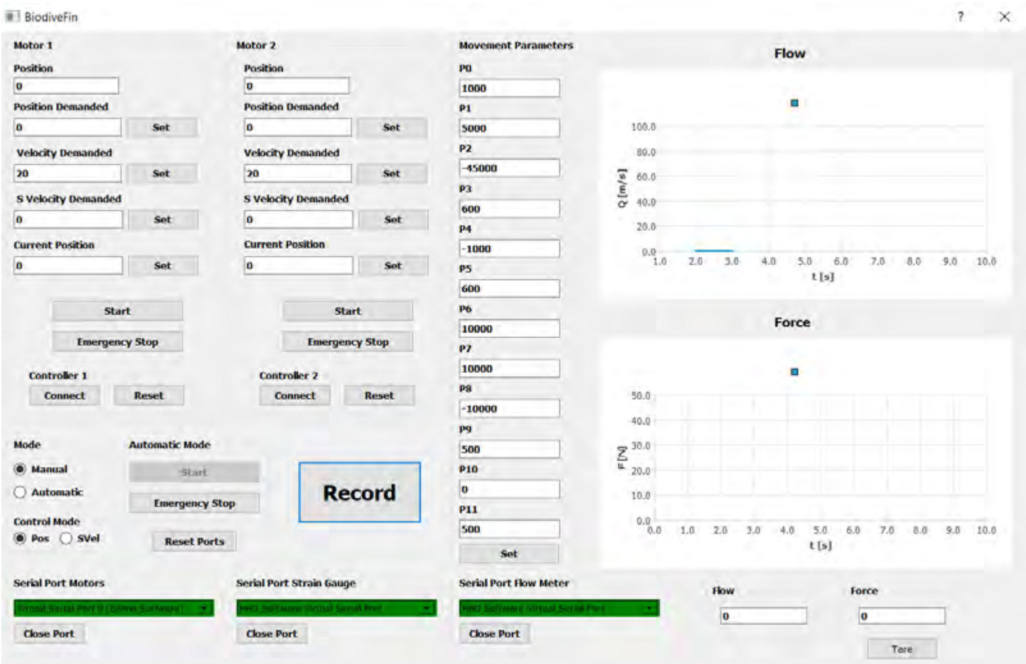

Figure 10 Graphical user interface

The user interface allows following operations:

- Manual and automatic control of the leg's positon.
- Connection between the motors controllers, the sensors and the control and measurement station.
- Recording data to a file.
- Tarring the thrust value.
- Visualisation data on the screen.

In order to ensure fast data transfer, the application is divided into three threads; each of them is running on a different core of a processor. The first thread is responsible for communication with a user and control over the other two threads. The second thread enables connection with the motors' controllers, whereas the third one is responsible for data gathering from sensors and writing it to a file.

The communication with motors' controllers is established using text commands based on the CiA specification DS309-3; this means that each text command consists of keywords and numbers that are separated by spaces. For example, if a new arm's position is needed, the following syntax should be used:

```
w m 0x00000201 4 0x00 0x00 0x00 0x00 <CR><LF>
```

where the last four bytes mean the new position.

One cycle of the communication function can be described in the following way:

- Check whether an error occurred, if yes, exit the function.
- Get data from the controllers.
- Calculate new positions of the arms.
- Send the new positions to the controllers.
- Wait 100 ms.

In order to calculate new positions of the arms, the movement pattern of a diver's leg was utilised. However, a direct implementation of designed method was impossible. It was connected with the fact that during the experiment the driver moved his leg not only in vertical direction but also in horizontal one. What is more, some technical limitations connected with mechanical construction as well as driver software demanded developing a new strategy of the movement estimation. The mechanical complication was due the fact that belt transmissions of two motors were located on the same shaft.

In view of this, the position of the second arm depended on the new position of the first one. On the other hand, the driver software problem results from delay in data transfer between miCAN-Stick2 CAN/USB and the motors' controllers because the smooth movement of the arms required exchanging data every 100 ms. The new positions, however, that were achieved by the motors after 1 second, reaching the established goal, based on the presented solution, proved to be impossible. On account of this, the prediction of future legs' positions was designed to be implemented in the control. Consequently, the following algorithm, based on 12 parameters, had been geared using the movement pattern and visual examination with comparison between human and robotic behaviour.

```
if(abs(motor_position1 - motor_positionDemanded1) < motor_controlParameters1 &&
abs(motor_position2 - motor_positionDemanded2) < motor_controlParameters2 &&
iterationNumber%2 == 1)
   {
    motor_positionDemanded1 = controlParameters3;
    motor_velocityDemanded1 = controlParameters4;
    motor_positionDemanded2 = motor_positionDemanded1*0.315-controlParameters5;
    motor_velocityDemanded2 = controlParameters6;//
    iterationNumber++;
   }
if(abs(motor_position1 - motor_positionDemanded1) < controlParameters7 &&
abs(motor_position2 - motor_positionDemanded2) < controlParameters8 &&
iterationNumber %2 == 0)
   {
    motor_positionDemanded1 = controlParameters9;
    motor_velocityDemanded1 = controlParameters10;
    motor_positionDemanded2 = motor_positionDemanded1*0.315 - controlParameters11;
    motor_velocityDemanded2 = controlParameters12;
    iterationNumber++;
   }
```

Data collection and recording were carried out in the third thread. At the beginning of the main function, the communication with the sensors is established. Subsequently, the following loop is executed:

- Sending inquire commands to the sensors in order to obtain measurement data("0x01,0x03,0x00,0x04,0x00,0x02,0x85,0xCA" for the flow meter and "S31;MSV?;" for the strain gauge).
- Receiving the measurement data.
- Saving obtained data to a file.

Due to the fact that the thrust force is obtained in the form of an integer number, which is proportional to the measured thrust, a calibration process was needed. In this process, the reference curve, depicted in Fig. 11, was obtained. However, although the integer number is proportional to the measured thrust, it is not equal 0 in the case when the thrust amounts to 0. Consequently, each measurement needs to begin with tarring, necessary to obtained proper data.

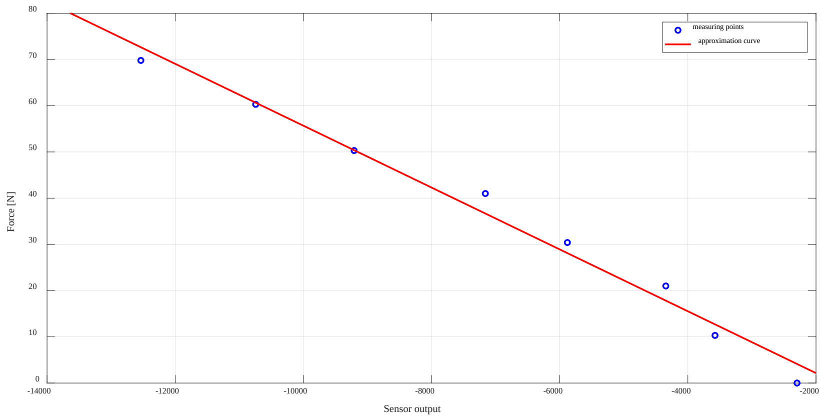

Figure 11 Strain gauge calibration

5. RESULTS

As mentioned previously, the aim of our work was to construct a test bench which facilitates conducting experiments in moving water. Therefore, the developed diver's artificial leg was placed in a water tunnel depicted in Fig. 12.

Figure 12 Water tunnel

The water tunnel was designed to allow a laminar flow of water during experiments; it was forced using a propeller presented in the figure below.

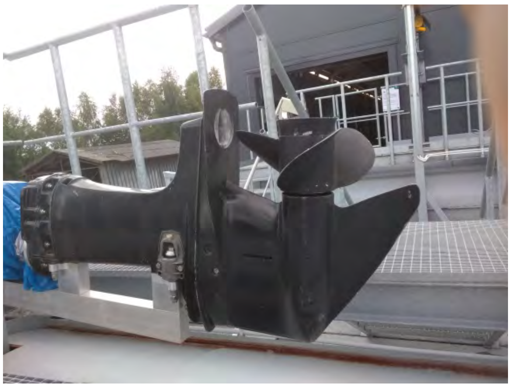

Figure 13 Propeller

In order to design movement models, the movement patterns as well as qualitative analyses of robotic leg's behaviour were employed during the initial test. As a result, a few movement models for some types of fins were designed. The exemplary movement parameters are presented in Table 1.

Table 1 Movement parameters

	Parameters											
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
Movement no. 1	1000	5000	-45000	600	-5000	600	10000	10000	-2000	400	0	400
Movement no. 2	1000	5000	-45000	500	-1000	500	10000	10000	-10000	300	0	300
Movement no. 3	1000	5000	-45000	700	-1000	700	10000	10000	-10000	500	0	500

The movement 1 parameters were designed for a large fin and fast motion. Angular positions of the arms during the experiment is illustrated by Fig. 14.

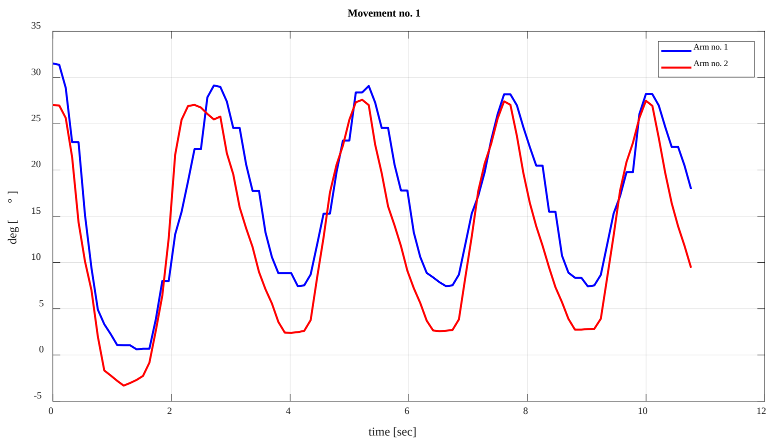

Figure 14 Movement 1 model

The movement model for the same fin but slower motion is presented in Fig. 15, whereas Figure 16 illustrates the model for smaller one and faster motion.

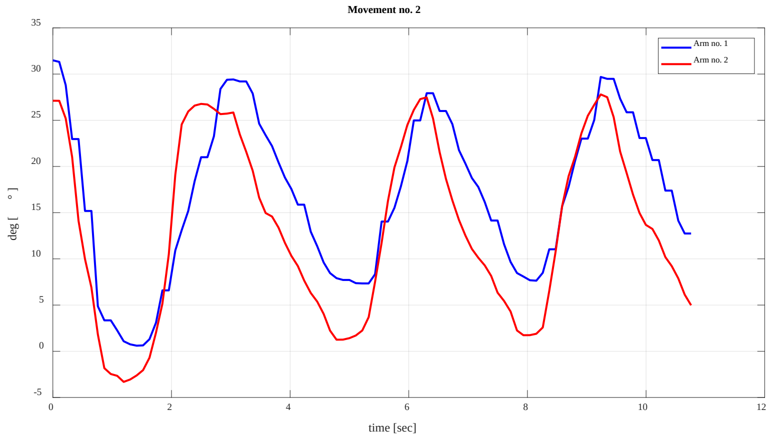

Figure 15 Movement 2 model

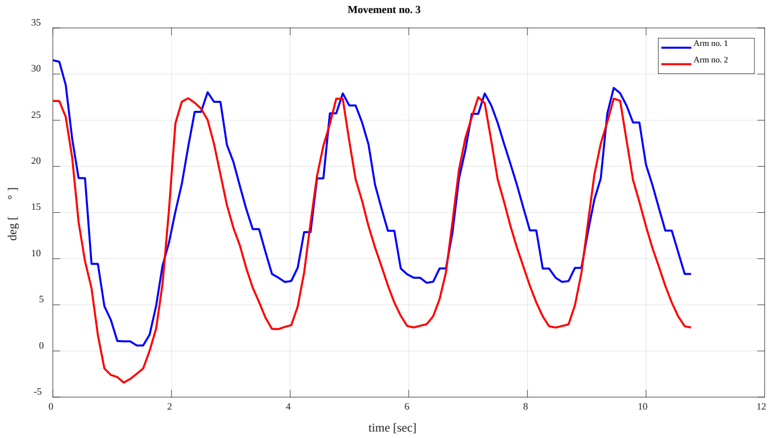

Figure 16 Movement 3 model

These results demonstrate that using the presented attempt, various movement models could be obtained. It should, however, be noted that due to technical difficulties related to a data transfer lag, movement of the first arm is not as smooth as the second one. Nevertheless, it will not affect future experiments in view of the fact that they will be concentrated on comparative analysis of tested fins.

6. CONCLUSION

Prior work has documented the need for developing a method of swim-fins efficiencies' calculation and comparison. On account of the fact that reproducible swimming technique is difficult to obtain due to the diver's fatigue during an experiment, an automatic solution is desirable to carry out experimentation with reliable results. Therefore, we have designed and developed the test bench, which enables carrying out experiments in flowing water.

In order to perform experiments, we have designed a measurement and control system for a diver's robotic leg, which has been developed based on movement pattern obtained using computer vision techniques as well as qualitative analyses of robotic leg behaviour during initial experiments. Our solution can be applied for testing a wide range of motions and fins' types utilising movement parameters implemented in the control algorithm.

ACKNOWLEDGMENT

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REFERENCES

[1] Bideau, N. *et al.*, „2D dynamical efficiency of a swimfin: a fluid–structure interaction approach", *Computer Methods in Biomechanics and Biomedical Engineering*, vol. 12, p. 53–54, 2009.
[2] El Baroudi, A. Razafimahery, F., „Fluid-Structure Interaction Effects on the Propulsion of an Flexible Composite Monofin", *Journal of Engineering*, p. 1–8, 2014.
[3] Marion, K., Guillaume, G., Pascale, C., Charlie, B., Anton, S., „Muscle activity during fin swimming", *Procedia Engineering*, vol. 2, p. 3029–3034, 2010.
[4] Morawski, M., Malec, M., Szymak, P., Trzmiel, A., „Analysis of Parameters of Traveling Wave Impact on the Speed of Biomimetic Underwater Vehicle", *Solid State Phenomena*, vol. 210, p. 273–279, 2013.
[5] Morawski, M., Malec, M., Zajac, J., „Development of CyberFish – Polish Biomimetic Unmanned Underwater Vehicle BUUV", *Applied Mechanics and Materials*, vol. 613, p. 76–82, 2014.
[6] Nakashima, M., Yoneda, T., Tanigawa, T., „Simulation analysis of fin swimming with bi-fins", *Mechanical Engineering Journal*, 2019.
[7] Nicolas, G., Bideau, B., Bideau, N., Colobert, B., Le Guerroue, G., Delamarche, P., „A new system for analyzing swim fin propulsion based on human kinematic data", *Journal of Biomechanics*, vol. 43, p. 1884–1889, 2010.
[8] Praczyk, T., Szymak, P., Naus, K., Pietrukaniec, L., Hożyń, S., „Report on Research with Biomimetic Autonomous Underwater Vehicle — Navigation and Autonomous Operation", *Scientific Journal of Polish Naval Academy*, vol. 213, p. 53–67, 2018.
[9] Praczyk, T., Szymak, P., Naus, K., Pietrukaniec, L., Hożyń, S., „Report on Research with Biomimetic Autonomous Underwater Vehicle — Low Level Control", *Scientific Journal of Polish Naval Academy*, vol. 212, p. 105–123, 2018.
[10] Praczyk, T., Szymak, P., Hożyń, S., „Applying Optical System to Model the Motion of Human Leg Moving in Water According to Swimming Style Crawl", *8th International Maritime Science Conference*, Budva, Montenegro, 2019.
[11] Szymak, P., Bruski, S., „Microprocessor System for Measurement of a Thrust Generated by an Underwater Vehicle", *Applied Mechanics and Materials*, vol. 817, p. 162–167, 2016.
[12] Szymak, P., Morawski, M., Malec, M., „Conception of Research on Bionic Underwater Vehicle with Undulating Propulsion", *Solid State Phenomena*, vol. 180, p. 160–167, 2011.
[13] Szymak, P., Przybylski, M., „Thrust Measurement of Biomimetic Underwater Vehicle with Undulating Propulsion", *Scientific Journal of Polish Naval Academy*, vol. 213, p. 69–82, 2018.
[14] Zhou, C., Low, K. H., „Design and Locomotion Control of a Biomimetic Underwater Vehicle With Fin Propulsion", *IEEE/ASME Transactions on Mechatronics*, vol. 17, p. 25–35, 2012.

THE OVERVIEW OF THE VARIED INFLUENCES OF THE SEAWATER AND ATMOSPHERE TO CORROSIVE PROCESSES

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Summary

This paper examines a rage of varied influences of the environment that affect nautical vessels during exploitation in order to investigate the possibility of the application of the new, smart materials in nautical industry. The specific conditions of the seawater and atmosphere as well as the operational conditions of vessels are examined on the basis of the previous research on the corrosive processes on vessels. The paper summarizes particular biological, chemical and physical parameters of the seawater and atmosphere in relation to the nautical data published so far. On the basis of the currently available database, the paper discusses numerous systematized and specific data regarding the influences of the seawater and atmosphere in Boka Bay and thus represents the ground for the realization of further research. The data about the seawater and atmosphere analyzed should foster the understanding of the numerous influences of the environment on the emergence of corrosion.

Keywords: corrosion, nautical vessels, see water, atmosfere,

1. INTRODUCTION

A rapid development of cruising and nautical tourism has led to the development of the numerous types of vessels used for different purposes including fishing, sailing, nautical tourism, etc. These vessels are characterized by high-quality construction technologies and protection as well as the highest standards of the quality and comfort of the systems installed. The strict quality and comfort standards require the usage of new materials that meet the safety, security and sustainability criteria in nautics. The varied branches of nautical industry, therefore, employ shape-memory materials in addition to the existing metals. The shape-memory materials are mostly the alloys of different metals based on copper, nickel and steel and are, thus, a subject of the research on the resistance to corrosion in different exploitational conditions. The understanding of the environment in which these materials are found is of the utmost importance for their further application in nautical industry.

Depending on the length of the operational cycle and the range of the spatial movements of vessels along coasts, within bays, river estuaries or at the open sea, the inner and outer structures of vessels are exposed to the specific conditions of the atmospheric and marine environment from outside and the conditions of exploitation from inside. The complex inner and outer factors determine the corrosive trends that usually appear on the exterior of vessels since the interior is usually equipped with adequate insulation layers that provide comfort and prevent the decay of constructions.

Being constructed for sports and entertainment, nautical vessels are primarily used during tourist season while the rest of the year vessels spend in marinas or different dry spaces. Although the time spent in marinas or dry spaces depends on the length of tourist season, it generally occupies a significant part of the year during which vessels are unused and exposed to the influences of corrosive environment. The corrosive environment can facilitate the corrosion of metals.

The aim of this paper is to provide an overview and the understanding of the importance of the factors that affect the beginning and progress of corrosion. The most relevant previous research focused on the influences of the corrosive processes on transport and commercial vessels (tankers and bulk carriers). In that regard, the paper will discuss the previously recorded specific influences of the environment on vessels in exploitation.

Extensive research was conducted in laboratory and real life conditions, while the first significant research on mild steel was conducted by Schumacher. Relying on the data about the exposure of steel in seawater, Schumacher described the main variables (e.g. temperature, salinity, pollutants, etc.) that affect the degree of corrosion [1]. Melcher developed a non-linear model of the degree of corrosion of mild steel in seawater and analyzed salinity, pH, seawater temperature and flow rate, the content of oxygen dissolved, sulfur pollution and fouling [2, 3]. Strekalov, on the other hand, mentioned variables like saline solution, relative humidity and temperature as the most important influences [4].

2. THE COPLEXITY OF THE ENVINROMENT OF NAUTICAL VESSELS

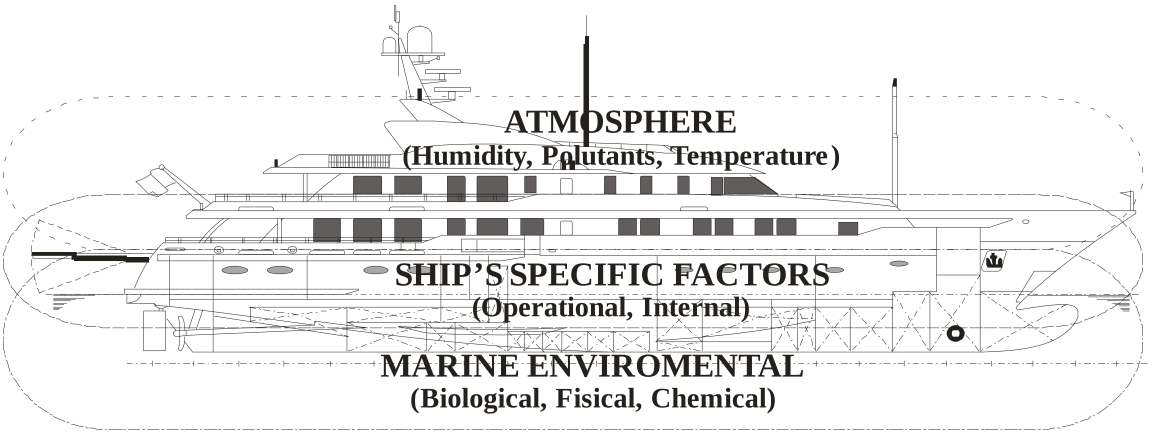
A general examination of the influences of the marine and atmospheric environment would correspond to the examination of the environment of the vessels through seven zones: the atmosphere (above flushed zone), flushed zone, ebb and flow zone, shallow waters (near the surface and coast), continental depth, deep oceans and mud [5]. However, considering the fact that vessels operate only on the surface of the sea, the research on the influences of the sea and atmosphere on ship structures encompasses four zones: immersed, flushed, ebb and flow zone, the atmosphere and semi-closed spaces [1, 6, 7].

The first zone includes the ship parts that are completely immersed into seawater which is saturated with oxygen. Pollution, dirt and flow rate have the main influence on corrosive processes. The biological activity of plant and animal species is at maximum, while the temperature on the surface is higher than at medium or great depths and varies depending on geographical location. The flushed zone is the most aggressive one due to the changeable cycles of exposure to seawater and the atmosphere. In case of the ebb and flow zone on the surface, corrosive materials are in touch with highly saturated seawater. This zone abounds in oxygen that facilitates corrosion.

The atmosphere contains sea salt particles which are by means of wind transported through the air. The changeability of the atmosphere and its influence on corrosive processes depend on altitude, wind speed and direction, dew formation, precipitation, temperature, solar radiation, dust, seasonal pollution, etc. Corrosion rate generally decreases in the vicinity of coasts [8].

The fourth zone comprises of closed atmospheric spaces on nautical or commercial vessels in operation since the closed, dry spaces or semi-closed spaces are the favourable environment for the emergence of corrosion due to operational or environmental conditions.

Besides the influences of the sea and atmosphere, commercial routes, geographical and other influences, internal factors such as surface protection systems and maintenance systems and the specificities of ships that characterize their operational cycle altogether increase the number of influential factors [9, 10, 11]. The identification of the numerous influential factors and the knowledge of exploitational conditions are a precondition for the prediction of potential corrosive damage and the overall understanding of corrosive processes.



Graph 1 The key factors affecting the corrosion of ship structures

The changeability of the environmental factors along with the operational characteristics of vessels can accelerate the decay of different ships elements or systems and especially materials such as shape-memory metals. Very often, only particular factors of the atmosphere, seawater or exploitational conditions accelerate the decay of metal structures, so the proper understanding of the complexity of the environment of nautical vessels has a major significance for the research on the intensity and influence of corrosion on metal structures. In that regard the, following sections of the paper will further examine the complex conditions of the environment of nautical vessels.

2.1. The Characteristics of Seawater that Facilitate Corrosion

Although seawater contains 96.5% of water and 3.5% of salt, dissolved natural gases and a few other particles [8], there is a plethora of factors that affect the intensity and rate of corrosion as well as the relationship between the two. There are biological, chemical and physical factors [12, 8].

2.1.1. Biological Factors

Biological organisms are present in almost every natural water environment. However, the activity of these organisms is most notable in river estuaries and warm seas i.e. on the surface zones where nautical vessels usually operate. Seawater organisms tend to deposit and stick to the surfaces of all structural materials, which leads to the formation of a thin biological film i.e. biofilm. Shallow waters have normal oxygen levels or are almost oxygen-saturated, while the biological activities of organisms are at maximum. Such circumstances can intensify corrosion and affect the change of environment and surface coatings. Similarly, it should be noted that the presence of biological organisms does not always have a dominant influence on corrosive processes [6, 8].

2.1.2. Chemical Factors

Various chemical factors were a subject of the extensive previous research with the aim of determining the significance and influence of those factors on corrosive processes. Many of the chemical factors, however, remained uninvestigated until today (e.g. sea pollutants).

Salt content. The main components of seawater are the same worldwide, thus the salinity at the open sea and the influence of the distance from the coast are considered constant. The salinity is usually expressed in per mille (‰) which indicates the content of dry salt in 1000g of seawater. The content of salt in seawater varies between 33 and 38 per mille [7].

Chlorides in seawater cause the formation of corrosive layers while the concentration of chloride as such affects the formation of pitting corrosion. The reduction in chloride content thus increases the critical potential of pitting while the expansion degree is decreased [8].

Mercer and Lumbard conducted the experiments that investigated the effect of small changes in salinity in calm seawater and proved that, in terms of corrosion rate, the effect of the changes is negligible [13]. Melcher also indicated that the decrease in salinity does not decrease the rate of corrosion [14], while Buzovkina and others claim that the decrease in salinity from 35% to 20 % leads to the increase in the degree of corrosion for 30% in case of carbon steel [15]. This conclusion is attributed to the changes in the salinity of seawater in natural conditions which follow other changes like solubility of oxygen and carbons.

The content of the oxygen dissolved. The concentration of the oxygen dissolved is not only related to temperature, but is also under the influence of flow rate, the length of contact with the atmosphere and biological activity. The plants growing on the sea surface cause the increase in the oxygen concentration through photosynthesis, while particular bacteria reduce the oxygen content to zero [16]. Depending on temperature, oxygen content varies between 8.0 ml/l on the surface of the Arctic waters and 4.5 ml/l in the waters of tropical regions. The minimum oxygen concentration in seawater varies between 0.01 and 0.40 mg.atm/l [17]. The amounts of the oxygen dissolved in ocean surface waters are in balance with the oxygen in the air at certain temperatures. However, the oxygen saturation of seawater is caused by the emergence of waves and the evolution of oxygen during the photosynthesis of microscopic sea plants, which usually happens during fouling periods in coastal areas. These circumstances can cause the over-saturation of the seawater with oxygen up to 10% [18].

The corrosion rates of active metals (e.g. steel) at a constant temperature in aggressive electrolytic environment such as seawater is a direct linear function of the concentration of the oxygen dissolved. In cases when temperature and oxygen vary (which is typical for seawater), oxygen has a greater effect on corrosion in comparison with temperature. The decrease in oxygen concentration to minimum decreases the degree of corrosion that is, in spite of the decrease in temperature, again increased at greater depths along with oxygen [17]. Melcher indicated the existence of a linear relationship between the oxygen dissolved and corrosion rate [19], while Fontana suggested a schematic diagram for the illustration of the influences of oxygen and oxides on corrosion [20].

pH Factor. pH value is defined as the tenth logarithm of the hydrogen ion activity [21]. Seawater is normally alkaline and the Ph value on ocean surfaces (where water is in balance with carbon dioxide form atmosphere) varies between 8.1 ad 8.3. The presence of the considerable amounts of hydrogen sulfide tends to reduce pH value and then water becomes sour.

Melcher showed that pH value varies depending on depth and indicated that at greater depths, due to thermodynamic processes caused by increased pressure, pH value decreases. He further claims that daily pH variations between 8.0 and 8.2 have negligible influence on corrosion, while the decrease in pH value can affect short-term corrosion [19]. Seawater is, most often, almost neutral ($4<pH<10$) and pH value does not play an important role when it comes to the corrosion of steel. In this case, the layer of oxygen and hydrogen tends to remain on surface so corrosion process is independent from pH [22].

The Conductivity of Seawater. The conductivity of seawater is the capacity of water to conduct electricity and equals approximately 5 S/m or 5.000.000 µS/m. Conductivity increases with the increase in temperature so high conductivity affects the intensity of corrosion. The dependence between conductivity and temperature is linear and triggers the increase in conductivity of 2% per Kelvin [23, 24].

2.1.3. Physical Fators

Seawater temperature, flow rate and pressure are the three most important factors affecting the corrosion of the elements immersed in the sea. Their influence varies from very important (temperature), over less important (flow rate) to undetermined (pressure).

Seawater temperature. The temperature on ocean surfaces depends on latitude and varies between – 2 ^{0}C at the poles and 35 ^{0}C on the equator. The annual variation in tropical regions is smaller than in the areas where the temperatures are around 10 ^{0}C [16]. In open systems such as seawater, where the oxygen dissolved can escape from water, corrosion rate increases along with temperature increase up to 80 ^{0}C. Subsequent decrease in corrosion rate at the temperatures above 80 ^{0}C is related to the decrease in oxygen solubility in seawater [22].

In closed systems such as ship ballast tanks, oxygen can disappear from environment and corrosion rate continues to increase along with temperature increase. If the concentration of the oxygen dissolved remains constant, the corrosion rate of low-carbon steel will double at every 30 ^{0}C [26]. According to a test series conducted in seawater at different temperatures, the corrosion rate of carbon steel at the temperature of 25 ^{0}C was almost double in comparison with the corrosion rate at 10 ^{0}C [16].

Melcher suggested two types of seawater: moderate and low-temperature seawater [17]. In moderate-temperature seawater, the first stage of corrosion is under the influence of electrochemical movements. Corrosion rate doubles at every 10 ^{0}C. At the stage of a controlled oxygen diffusion, the increased temperature of water reduces the solubility of oxygen in seawater while the possibility of oxygen diffusion through the surface layers of corrosion is reduced. In these conditions, the increase in temperature of around 30 ^{0}C is necessary to double the rate of corrosion [27]. The temperatures below 5 ^{0}C do not affect corrosion rate.

Based on natural and artificial seawater, Mercer and Lumbard proved that corrosion increases at the temperatures above 10 ^{0}C and then gradually decreases as the temperature reaches the boiling point [13]. At the sea temperatures below the range between 5 ^{0}C and 10 ^{0}C, corrosion rate tends to increase in accordance with short-term laboratory observations [13, 25].

Flow rate. A changeable flow rate can increase the degree of corrosion, which is a consequence of the accelerated decay of the surface protective coatings as well as the increase in the amount of the oxygen dissolved that touches metal surfaces. An increased flow rate of water particles can increase the corrosion rate of carbon steel – the flow rate of 1 m/s doubles corrosion rate [16].

Uhlig and Revie confirmed that the corrosion rate in seawater is proportionate to flow rate up to critical flow rate values, but after that, the change in corrosion rate is negligible [22]. Melcher's short-term research indicated that the corrosion of the steel immersed into seawater increases along with the increase in flow rate. However, in cases of longer exposure, the corrosive layer formed acts as surface protection, so flow rate continues to affect corrosion with slow rate [28]. Fontana presented a schematic relationship between flow and corrosion rates of different metals [20].

Pressure. The importance of the pressure of seawater is described through a hydrostatic equation that represents the relationship between pressure and depth. Under the assumption that water density is constant, the equation of hydrostatic pressure indicates a proportionate relationship between pressure and depth [8]. The impact of pressure on corrosion is negligible since ship structures operate only in sea and ocean surface zones.

2.2. The Influence of the Exposure to the Atmosphere on Corrosion

The influence of the atmosphere on corrosion of ship parts and systems is so far investigated through air humidity, temperature and specific air pollutants.

Air Humidity. Air humidity is characterized by relative humidity, absolute humidity, moisture content and specific air humidity [29]. The primary value of critical relative humidity is the value under which the corrosion of metals is nonexistent. In that sense, a very slow corrosion begins at the relative humidity of 60% [30], while a rapid increase in corrosion rate happens at the relative humidity between 75% and 80% as a consequence of moisture condensation inside rust [31]. At the relative humidity of 90% corrosion rate is further increased, which corresponds to the pressure of the vapor of saturated ferrous sulfate solution as it becomes corrosive [32].

Air Temperature. The increase in temperature facilitates corrosion by means of the acceleration of electrochemical reactions and diffusion processes. At constant humidity levels, the increase in temperature will accelerate corrosion. However, the increase in temperature will mostly reduce relative air humidity and accelerate the evaporation from electrolyte surfaces. When humidity time decreases, the total corrosion rate is decreased, as well [33].

Specific Air Pollutants. The thin layer of electrolytes on metal surfaces contains different materials that emerged during corrosion of metals or were deposited from the atmosphere. The composition of electrolytes is often a factor that determines the direction of corrosive processes. The composition of the air regularly involves oxygen which facilitates oxidation and is easily absorbed in a thin layer formed on metal surfaces. Numerous experiments showed that severe corrosion can emerge and cause the damage of iron alloys whose oxygen content is between 8% and 15% at the temperature between 3 ^{0}C and 500 ^{0}C [34].

2.3. The vessel-Specific Factors Affecting Corrosion

On the basis of the forms of corrosion that occur in marine and atmospheric conditions, cargo holds, ballast tanks or dry spaces, it is evident that the factors related to the operational and exploitation conditions affect corrosion.

Research done by Paik, Melcher and Gardiner [5, 9, 10] on mechant vessel show that operation and internal factors have important influence on corrosion rate.

Operational Factors. Operational factors of the usage of nautical vessels are related to the degree of vessel exploitation i.e. the time of their operation and rest. The rest time implies berthing in marinas or at sea as well as dry, while the operation time implies the active usage of vessels during nautical season. During the navigation at the open sea or along the coast, vessels are exposed to specific conditions of the sea and atmosphere, which can, in the long run, affect the intensity of corrosion. The influence of the sea routes in case of commercial ships was a subject of extensive research that aimed to define the risk of the routes on the one hand and the influences of the environment on the corrosive processes of ship parts on the other hand [11, 18, 35].

Internal Factors. Nautical vessels that are exposed to the same exploitational conditions, but were differently designed and maintained, could be exposed to accelerated corrosive processes due to various factors that are characteristic for a particular navigational structure. In that sense, the most relevant internal factors are corrosion protection systems, specific insulation systems and the degree of vessel exploitation for varied purposes (personal, commercial usage, etc.) throughout the year.

3. THE INFLUENCE OF THE SEA WATER AND ATMOSFERE IN BOKA BAY

With the aim of the realization of the PROCHA-SMA project, the paper analyzes concrete parameters of the sea and atmosphere in the Bay of Tivat as a part of Boka Bay. The data refers to a longer period of measuring and is based on the research that relevant institutions conducted in the Bay of Tivat so far.

The locations where the measuring was performed are in the northern and southern part of the Bay of Tivat. The northern location is Porto Montenegro marina and its surrounding while the southern one is Obala Đuraševića. The measuring was conducted between 2010 and 2017 by the Institute of Marine Biology of the University of Montenegro for the purposes of various legal persons. The paper analyzes the available data in order to precisely define the outer influences of the sea and atmosphere on the corrosive processes of the new, smart materials.

The specificities of the micro-location i.e. the Bay of Tivat are based on the fact that all the research-relevant data regarding the climatography were gathered in a diameter of five kilometers. More precisely, the micro-location observed spanned between Tivat Airport where atmospheric conditions were analyzed and two other locations (Porto Montenegro marina and Obala Đuraševića) where the analysis was directed toward the marine environment [36, 37].

3.1. The Analysis of the Marine Parameters

The measuring of the parameters of the marine environment in Porto Montenegro marina was based on the measuring of seawater temperature, conductivity and salinity on the surface and at the depth of 5m. The measuring was performed in three locations (inside and in front of the marina and in the Bay of Tivat) once a month in the period of two years - between March, 2015 and March, 2017. The data regarding the average, minimum and maximum values for the three parameters are presented in Table 1a, 1b and 1c [37].

Table 1.a The average values of the marine parameters in the three locations for the period between 2015 and 2016

The average values in three locations 2015-2016													
Loc. 1-3	2015-16	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Dept: 0,0	Temperature	10.7	12.7	14.4	17.1	20.4	24.22	27.1	25.4	23.7	17.9	17.1	17.6
	Conductivity	50.4	39.5	48.4	52	48	54.32	52.6	53.1	52.6	32.7	50	50.5
	Salinity	33.1	28.1	30.7	33.9	30.8	36.17	34.7	35.1	33.2	21.8	31	33.7
Loc. 1-3	2015-16	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Dept: 5,0	Temperature	10.5	14.2	15.6	17.3	19.9	22.98	26.2	24.3	23.9	20.8	19.2	17.5
	Conductivity	50.9	51.3	51.5	52.5	50.7	54.47	54.6	54.6	54.2	52.3	52.8	52.5
	Salinity	34.2	34.6	33.7	34.5	33.2	36.25	36.6	36.5	36.1	33.1	34.7	35.2

Table 1.b The maximum values of the marine parameters in the three locations for the period between 2015 and 2016

The maximum values in three locations 2015-2016													
Loc. 1-3	2015-16	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Dept: 0,0	Temperature	11.8	14.7	14.8	18	21.7	26.4	28.6	27.5	24.7	21.3	19.6	18.3
	Conductivity	50.5	47.6	51	54.4	52.8	54.7	53.2	55	54.5	33.8	53.9	50.9
	Salinity	35.2	31.5	33	36.2	34.9	36.4	35.3	37	36.3	25.4	35.9	37
Loc. 1-3	2015-16	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Dept: 5,0	Temperature	11.9	14.7	19.2	18	21.7	24.1	27.5	27.1	24.5	21.2	20	18
	Conductivity	51.1	52.6	53.6	54.8	53.7	54.7	55.6	55.3	54.8	55.6	54.8	52.6
	Salinity	35.8	36	35.6	36.5	35.7	36.5	37.5	37.1	36.7	34.4	36.5	37

Table 1.c The minimum values of the marine parameters in the three locations for the period between 2015 and 2016

The minimum values in three locations 2015-2016													
Loc. 1-3	2015-16	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Dept: 0,0	Temperature	9.3	11.2	14	16.5	19.7	22.4	25.8	22.5	22.8	12.4	14.5	16.1
	Conductivity	50.3	35	42.1	48.2	40.8	53.9	52.1	51.4	50.4	31.8	46.4	50
	Salinity	31.3	21.9	26.3	30.1	24.8	35.9	34.1	33.4	31.9	17.8	26.3	32.1
Loc. 1-3	2015-16	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Dept: 5,0	Temperature	9.3	13.7	14.5	16.4	17.6	21.3	24.9	21.2	23	20.1	18.3	16.2
	Conductivity	50.5	50.5	47.8	48.6	41	53.5	53.6	52.1	53.7	49.2	49.8	52.4
	Salinity	32.4	32.4	29.7	30.6	25	35.5	35.6	34.1	35.7	29.1	31.8	34.4

The measuring of the parameters in Obala Đuraševića was performed in the period between March, 2010 and June, 2016 - once a month for each month except June, July and August when the measuring was performed twice a month. The depth of measuring was 0.5m from the sea level and the data about the average, minimum and maximum values of the parameters examined are presented in Table 2 [36].

Table 2 The average, minimum and maximum value of the marine parameters in the second location

Obala Đuraševića - the ocation of measuring													
AVGERAGE	2011-16	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Dept:0,5	Temperature	11.4	13.0	15.5	16.8	21.0	24.2	25.3	26.1	23.2	18.8	17.4	15.2
	Conductivity	41.7	33.4	46.4	48.0	47.3	48.2	54.6	54.8	54.5	48.9	43.3	48.3
	Salinity	26.8	21.6	29.5	31.1	30.7	31.5	36.0	36.3	36.0	31.4	27.6	31.4
MAXIMUM	2015-16	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Dept: 5,0	Temperature	14.0	15.0	21.5	18.0	25.9	27.6	28.6	28.1	26.0	21.6	19.8	17.1
	Conductivity	52.2	42.4	52.2	53.8	52.6	54.4	56.4	56.9	57.3	54.6	49.4	55.5
	Salinity	34.6	26.9	34.5	35.8	34.7	36.2	37.5	37.9	38.2	36.1	31.6	36.8
MINIMUM	2015-16	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Dept: 5,0	Temperature	6.1	10.3	12.7	15.2	17.0	15.2	23.4	23.8	19.1	16.1	14.2	12.0
	Conductivity	15.6	21.1	33.8	34.5	41.6	18.0	52.6	52.6	52.2	33.6	34.8	35.0
	Salinity	7.9	16.7	19.6	21.3	25.9	10.6	34.7	34.7	34.0	19.4	22.6	22.8

3.2. The Analyses of the Parameters of Climatography

The climate graphs from Tivat Airport were drawn on the basis of the data available from the observations in the period of ten years, between 1985 and 1994. The data gathered in the aviatic weather station of Tivat Airport correspond to the norms prescribed, although certain modifications were made for the purposes of a better overview of the characteristics of particular meteorological parameters. Meteorological characteristics are based on the interpretation and analysis of daily observations of air temperature, pressure, humidity, cloudiness, wind and other atmospheric features. The content analyzed is prescribed by the Technical Regulation of the World Meteorological Organization and the International Civil Aviation Organization for Civil [38].

The airport is located in a lowland area, on the coast, at the bottom of the Bay of Tivat at six meters above sea level. The distance from the sea is only several hundred meters while altitude and longitude are 420 24' 15'' N and 180 43' 41'' E.

3.2.1. Air Temperature

Table 3 exhibits the average monthly and annual air temperatures, the extreme values of air temperature and the average number of days with characteristic air temperatures in the period observed. Due to a direct influence of the sea, none of the months observed has a negative average value. The average value of the temperature during the coldest month (January) was 6.7 ^{0}C while during the warmest month (August) the average temperature was 24.6 ^{0}C. The average annual temperature equaled 15.1 ^{0}C [38].

Table 3. The average monthly and annual air temperatures and the extreme average values of air temperature

Temperature / Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Avg.
The average monthly and annual temperatures	6.7	7.5	10.0	13.2	17.7	21.2	24.5	24.6	20.5	16.2	11.4	7.3	15.1
The absolute maximum air temperature	20.0	24.8	25.7	27.0	30.0	34.8	37.6	38.2	34.2	30.2	24.5	18.5	38.2
The absolute minimum air temperature	-6.5	-8.2	-5.6	-0.2	2.6	8.2	11.8	11.0	5.5.	0.4	-3.2	-6.5	-8.2

3.2.2. Relative Humidity

The average values of relative humidity per month vary between 63% (July and August) and 78% (January), while the average annual value was 71%. All the values are exhibited in Table 4. The absolute minimum was recorder in March and equaled 12%. The minimum values of the relative humidity follow the maximum values of air temperature during the day (53% at 2 p.m.), while the average values of relative humidity that exceed 80% were recorded every month at the early hours and during the night [38].

Table 4. The average monthly and annual values of relative humidity and the absolute minimum values

Relative humidity / Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Avg.
The average relative humidity per month and per year	78	71	72	72	70	69	63	63	71	75	77	75	71
The absolute minimum value of relative humidity	15	13	12	16	14	19	18	18	15	17	14	14	12

3.2.3. Wind

The vicinity of the sea and mountains contributes to a specific character of the Bay when it comes to winds. The SE wind direction is prevalent almost throughout the year, with the exception of May, June and July when the WSW direction is more frequent. The SE, ESE, SSE and S directions are relevant for 32.5% of the winds observed, while twelve other directions (out of the sixteen wind directions according to compass rose) constitute the remaining 67.5%. Considering wind speed throughout the year, it is estimated that faster winds blow from N, NNE and NE and that certain winds during February and March exceed the speed of 13 m/s. The periods without winds are the least notable in June (18.8%) and the most notable in December (29.0%) [38].

The annual compass rose shows the frequencies (%) of the winds whose speed varies between 1 and 4 m/s, 5 and 8 m/s and exceeds 9 m/s and further classifies the winds according to their directions [38].

Precipitation is the most frequent with southern winds (19.4% per year) with the highest frequency in March and the lowest in July. The frequency over 10% occurs with the SE and SSE wind directions, while the least frequent precipitation occurs with the SW wind directions (1.5%). The periods without winds are followed by an increased frequency of precipitation (9.8%).

The data presented implies that, due to the specificities of the Bay as such and the presence of southern and northern winds, a high concentration of seawater particles is present in the air near the sea throughout the year. This establishes the fact that the atmosphere is under a significant influence of the marine environment, both inside the Bay and in the south, outside of the Bay.

3.2.4. Other Influences

Other influences refer to atmospheric pressure and specific weather phenomena.

Atmospheric pressure is, along with temperature and humidity, significant for the determination of air density. Therefore, in the area observed the average monthly values of atmospheric pressure vary between 1012.8 hPa in April and 1019.5 hPa in January. Atmospheric pressure values are most often in the range between 1010.0 hPa and 1014.9 hPa (54.1%) in July.

Specific weather phenomena involve precipitation (rain) and thunders which occur throughout the year and affect metals which are not relevant for this research. Fog and snow occur rarely and are, due to the vicinity of the sea, less relevant for corrosive processes.

3.3. Data Analyses

Considering the data regarding the average, maximum and minimum monthly temperatures of seawater, it is evident that, in both locations observed (Porto Montenegro and Obala Đuraševića) there are not significant aberrations in the seawater temperature on the surface and at the depths of 0.5m and 5m. The tables show that the difference in temperature in the locations observed was less than 1 ^{0}C with the exception of February, March, October and November when the aberration exceeded 1 ^{0}C. The maximum monthly aberration was recorded in October and equaled 2.9 ^{0}C. The difference between the average values of temperature in both locations is usually around 1 ^{0}C, with the exception of December when aberration was the greatest – 2.4 ^{0}C. These observations indicate that, regardless of the difference in the location and depths observed, aberrations in seawater temperature in the Bay of Tivat correspond to the approximately same reference values.

The data about conductivity indicate a negligible difference between the locations and depths observed. More significant aberrations were recorded in February and October when the variations in conductivity are drastic and the values recorded were as low as 31.8 mS/cm. Likewise, conductivity decreases during winter as a consequence of an increased amount of freshwater.

Salinity is lower on the surface in comparison with the values recorded at the depth of 5m. However, depending on the year of measuring there are certain aberrations in the values recorded on the surface and at the depth of 0.5m. More significant aberrations were recorded during February and October when, due to the increased precipitation, the inflow of freshwater increases and thus reduces the salinity in all locations. In winter, for example, the salinity is reduced below 10% (the lowest value of 7.9‰ was recorded in January).

Air temperatures are, on average, always above zero with a tendency of reaching 40 ^{0}C during summer. The comparison between the mean of the average values of the sea and air temperatures in the locations observed indicates that the average monthly temperatures of the sea are higher than the average temperatures of the air. The increase in the monthly temperature values varies between 0.8 ^{0}C for August and 10.3 ^{0}C for December. Likewise, the maximum temperatures of the sea are considerably lower than the maximum monthly air temperatures that vary between 0.2 ^{0}C in December and 10.9 ^{0}C in March. The minimum sea temperatures are, on the other hand, significantly higher than the minimum air temperatures that vary between 12.0 ^{0}C in October and 22.6 ^{0}C in December. This indicates notably lower aberrations in the sea temperature in comparison with the air temperature.

The winds in the area observed and the increased humidity throughout the year contribute to the climatic conditions that seriously affect corrosive processes of all metal structures, both at sea and near it.

4. CONCLUSION

The paper summarizes the key influences of the sea and atmosphere on corrosive processes on the basis of the research conducted so far by numerous maritime authors. The paper presents different biological, chemical and physical influences of the sea as well as the influences of temperature, atmospheric pressure, relative humidity and wind in a specific location such as Boka Bay.

The data about seawater show that there are not any significant aberrations in the values obtained on the sea surface and at the depth of 0.5m and 5m in terms of sea temperature and conductivity, while more significant aberrations were notable in case of salinity. The aberrations in temperature, conductivity and salinity are in the range between 5% and 10%.

The atmospheric observations indicate a strong presence of winds throughout the year which implies that all vessels in marinas or winter storages are exposed to the influences of the sea. Similarly, the changes in air temperature are less notable in comparison with the changes in sea temperatures whose variations are considerably lower. On the contrary, the average sea temperatures are higher than the average air temperatures per month.

The overview of the influential parameters of the sea and atmosphere in Boka Bay should assist the further research on the application of new materials in nautical industry and the resistance to corrosion depending on their location and exposure to corrosive environment. The data regarding the conditions of the environment can contribute to the determination of the importance of the environmental conditions for the corrosion of metals.

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REFERENCES

[1] Schumacher, M.: Seawater corrosion handbook, NJ: Noyes Data Corporation, 1979

[2] Melchers, RE.: "Corrosion uncertainty modelling for steel structures", J Construct Steel Res, Vol. 52, No. 1, 1999, pp. 3–20

[3] Melchers, RE.: "Factors influencing the immersion corrosion of steels in marine waters", Proceedings of the 14th International Corrosion Congress, Cape Town, South Africa, Paper 98, September 1999

[4] Strekalov, PV.: "The atmospheric corrosion of metals by adsorbed polymolecular moisture layers", Protect Met, Vol. 34, No. 6, 1998, pp. 501–19

[5] Paik, J. K., Kim, S. K., Lee, S. K.: "A probabilistic corrosion rate estimation model for longitudinal strength members of bulk carriers", Ocean Engineering, Vol. 25, No. 10, 1998, pp. 837–860

[6] Heidersbach. R.H.: "Marine corrosion - Specific Industries and Environments", Corrosion, ASM metals hand book, Vol. 13, 1986, pp. 893–926

[7] Ivošević, Š., 2012. PhD Thesis, University of Montenegro, Maritime Faculty Kotor, Kotor, Montenegro.

[8] Venkatesan, R.: "Studies on corrosion of some structural materials in deep sea environment", Dissertation, Indian Institute of Science, Bangalores, 2000

[9] Gardiner, C.P., Melchers R.E.: "Bulk Carrier Corrosion Modelling", Proceedings of the Eleventh International Offshore and Polar Engineering Conference Stavanger, Norway, June 17–22, 2001

[10] Gardiner, C.P., Melchers R.E.: "Corrosion analysis of bulk carriers, Part I: operational parameters influencing corrosion rates", Marine Structures, Vol.16, 2003, pp. 547–566

[11] Gudze, M.T., Melchers, R.E.: "Operational based corrosion analysis in naval ships", Corrosion Science, No. 50, 2008, pp. 3296–3307

[12] Melchers, Robert, E.: "Advances in Mathematical-Probabilistic Modelling of the Atmospheric Corrosion of Structural Steels in Ocean Environments", 3rd International ASRA Net Colloquium, Glasgow, UK, 10–12th July 2006.

[13] Mercer, A., Lumbard, E.: "Corrosion of Mild Steel in Water", British Corrosion Journal, 1995, pp. 43–55

[14] Melchers, R.: "Modeling of Marine Immersion Corrosion for Mild and Low–alloy Steels– Part 1 Phenomenological Model", Corrosion, 4, 2003c, pp. 319–334

[15] Buzovkina, T., Aleksandrov, V., Loginov, V., Egorov, E., Yurchenko, A.: "Effect of Alkalinity of Water and Carbonates on the Initial Stages of Steel Corrosion in the Sea of Japan and the Black Sea", Prot. Met., 1990, pp. 510-512
[16] Chandler, K.: Marine and Offshore Corrosion, Butterworths Ltd, 1985
[17] Melchers, R.: "Probabilistic Models of Corrosion for Reliability Assessment and Maintenance Planning", Proceedings of the 20th International Conference on Offshore Mechanics and Arctic Engineering, OMAE2001/S&R-2108, 2001
[18] Guedes Soares, C., Garbatov, Y., Zayed, A., Wang, G.: "Non–linear corrosion model for immersed steel plates accounting for environmental factors", Transactions SNAME, Vol. 115, 2005
[19] Melchers, R.: "Effect on Marine Immersion Corrosion of Carbon Content of Low Alloy Steels", Corrosion Science 45 (11), 2003a, pp. 2609-2625
[20] Fontana, M.: Corrosion Engineering, McGraw Hill Book Company, 1992
[21] Robinson, R., Stokes, R.: Electrolyte Solutions, 1959
[22] Uhlig, H., Revie, R.: Corrosion and Corrosion Control, Wiley, 1985
[23] Gray, James R. (2004). "Conductivity Analyzers and Their Application". In Down, R. D.; Lehr, J. H. (eds.). Environmental Instrumentation and Analysis Handbook. Wiley. pp. 491–510. ISBN 978-0-471-46354-2.
[24] "Water Conductivity". Lenntech. Retrieved 5 January
[25] Melchers, R.: "Mathematical Modeling of the Diffusion Controlled Phase in Marine Immersion Corrosion of Mild Steel", Corrosion Science, 45, 003b, pp. 923–940
[26] Korb, L., Olson, D.: Eds Metals Handbook, Corrosion, 13, Ninth Edition, 1987
[27] Lisseling, F.: "General Guidelines for Corrosion Testing for Marine Applications", British. Corrosion Journal, 1989, pp. 55–78
[28] Laque, F.: Marine Corrosion, Causes and Prevention, John Wiley & Sons, 1975, pp. 63–70
[29] Natesan, M.: PhD Thesis, Anna University, Chennai, India, 1995
[30] Skorchelletti, V.V.: Tukachinsky, S.E., J. Appl. Chem., 28:615, 1955
[31] Barton, K., Bartonova, Z.: Werkst. Korros., 21:85, 1970
[32] Schwarz, H., ibid., 16:93, 1965
[33] Roberge, P.R.: Handbook of Corrosion Engineering, McGraw-Hill, USA. 58, 1999
[34] Karlsson, A., Moller, P. J., Vagn, J., Corrosion Science, 30:153, 1990
[35] Stephen, E., Roberts, P., Marlow, B.: "Casualties in dry bulk shipping (1963–1996)", Marine Policy, Vol. 26, 2002, pp. 437–450
[36] Institut za biologiju mora (2011-2016), Izvještaj o monitoringu i bio monitoringu kvaliteta vode za arikulturu. Ministarstvo poljoprivrede i ruralnog razvoja Crne Gore. Godišnji izvještaj. 85p.
[37] Institut za biologiju mora (2016), Izvještaj o monitoringu stanja životne sredine u akvatorijumu marine Porto Montenegro. 125p.
[38] Klimatografija aerodroma Tivat, Savezni hidrometeorološki zavod, SRJ, Beograd 1999.godine. Svi sadržaji su propisani Tehničkim regulativama Svjetske meteorološke organizacije i Međunarodne organiazcije za civilno vazduhoplovstvo.

USE OF MARITIME TRANSPORT BY POLISH ARMED FORCES - EXPERIENCE AND FUTURE

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Summary

For the development of the use of sea transport in the process of transferring troops, the ability to satisfy the reported needs is of key importance. It should be noted that nowadays the acquisition of means of sea transport can be secured from the following sources: naval vessels of the Polish Navy; warships and transport vessels of the armed forces of other countries - made available on the basis of bilateral agreements or agreements; warships or civilian transport vessels obtained through the participation of the Polish Armed Forces in multinational NATO and European Union programs; commercial civilian ships chartered (contracted) from Polish or foreign sea carriers. Such a wide range of possibilities creates real conditions to pay special attention to sea transport in the process of building strategic transport capacity for the national armed forces and allied coalition forces. The aim of the paper is to identify the scale of the phenomenon of maritime transport in the Polish Armed Forces over the last 10 years and to indicate the directions of development of maritime transport used during military operations. The structure of the article covering the three basic parts is subordinated to the purpose of the work. The first one refers to the conditions of using maritime transport for the needs of the armed forces, the second identifying the scale of the analyzed phenomenon and the third one, prognostic indicating the potential development directions of this extremely important sphere of functioning of each army.

Keywords: transport, sea, armed forces, logistics

1. INTRODUCTION

Geopolitical conditions and related military operations rapidly changing for a dozen or so years require relocation of soldiers, their weapons and equipment over long distances. As previous experience has shown, the success of military operations in numerous cases depends on the capacity of strategic transport. It is carried out virtually with all branches of transport, but in the case of heavy equipment, it is the maritime transport that dominates. Regarding high military relocation costs by air transport - and this is how only the personnel is transported - the military equipment as well as combat means, and materials are in vast majority of cases transported by sea. The performed analyses unequivocally show that the costs of transporting the military and equipment by sea are about 20 times lower than those of air transport, and at the same time it is of mass nature.

The paper is intended to identify the scale of the maritime transport phenomenon in the Polish Armed Forces over the last decade, and to indicate the developmental directions employed during military operations. The undertaken research problem has been determined in the following shape: What is the role currently played by maritime transport in relocation of soldiers and military equipment within the Polish Armed Forces and what is the direction it should be developed in the nearest future? The article structure covering three main parts is subjected to the purpose of the work. The first one is related to conditions of using the maritime transport for the armed forces' needs; the second one identified the scale of the analyzed phenomenon; and the third one, of a forecast nature, determines the potential developmental directions of this extremely significant sphere of each army functioning.

2. CONTEMPORARY CONDITIONS OF USING MARITIME TRANSPORT FOR THE NEEDS OF ARMED FORCES

Maritime transport is employed for mass transportation of troops, in particular heavy armaments, military equipment as well as supplies. The carriage of personnel usually includes convoys of operations and drivers of the transported equipment. It should be noted here that such features of maritime transport as: extended transport possibilities (tonnage), multitasking, range and relatively low costs means that it is mainly used for strategic relocation of weapons and military equipment along with supplies. However, it does not constitute a primary means of personnel relocation, except for crews and operators of the transported armaments and military equipment as well as amphibious landing forces. The main limitation of maritime transport is low speed, susceptibility to damage and long embarkation and disembarkation times. The following means of maritime transport can be adopted to carry the equipment and materials of the Polish Armed Forces [6]:

- ro-ro (roll on - roll off) ships - mainly for the transportation of armaments, wheeled and tracked equipment;
- container ships - for the transportation of cargo in transport containers;
- general cargo shis - when properly adapted, they can be used to carry the cargo in transport containers as well as the armaments and self-propelled equipment;
- tankers - used primarily for carrying fuels;
- passenger ships (ferries) - for the carriage of persons;
- minelayer-landing ships of the Polish Armed Forces - for the carriage of cargo in transport containers as well as the armament and equipment, according to their technical capabilities.

The Polish Armed Forces use the means of transport and transport infrastructure available within [10]:

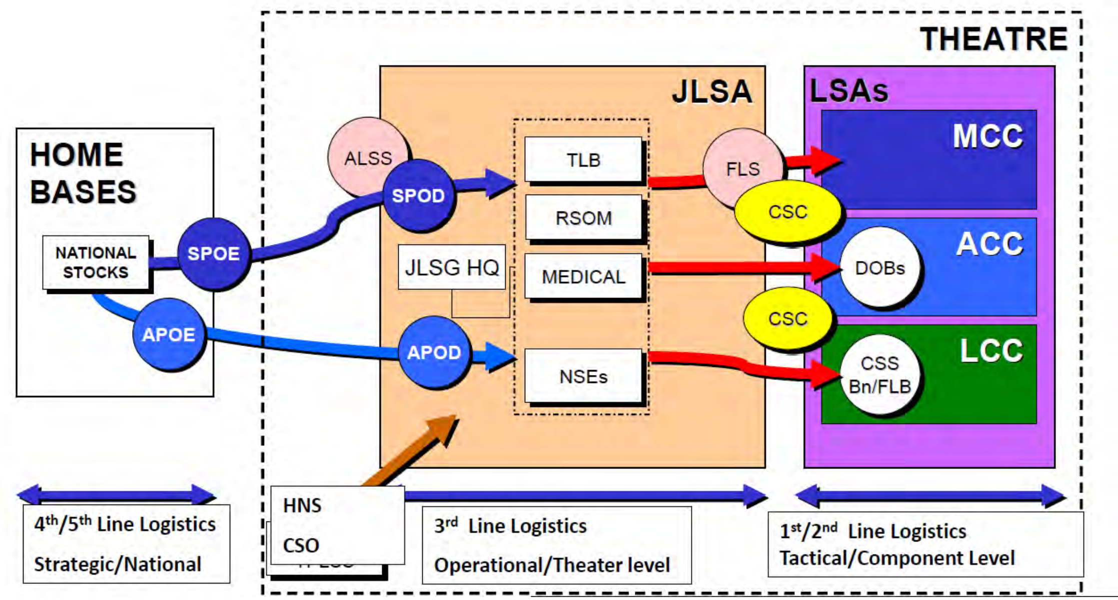
- own resources available to particular types of armed forces;
- obtained access to the resources of the armed forces of other countries pursuant to the bilateral or multinational arrangements and agreements;
- participation in multinational cooperation programs;
- support from external counter parties according to the arrangements and agreements made on market terms;
- support for the national economy implemented by the economic defense cells of the non-military subsystem according to the general defense obligation.

Factors determining the scope of application of the maritime transport [10]:

- identified transport requirements, including the size of the forces that must be relocated;
- distance of the relocation along with specific time regimes;
- numbers and transport capabilities of the available vessels and ships;

- availability of appropriate seaports, in particular the ports of disembarkation near or in the theatre of operations;
- capacity of the ports of disembarkation and transport infrastructure;
- applicable formal and legal conditions concerning the maritime transport, including the regulations on the transport of dangerous goods;
- availability of material handling equipment ;
- availability of escorting ships.

It should be stressed that the concepts of logistics safeguarding of NATO and EU operations provide for the use of the maritime transport for the transfer of troops to and from the area of operations. Figure 1 presents an organizational scheme for the relocation of troops. This process begins in the ports of embarkation where heavy equipment and materials are loaded onto the ships, which they are transported on to the ports of disembarkation usually located in the countries outside the conflict zone. Significant role for efficient loading and unloading in the ports will be played by the port infrastructure, availability of specialist devices and logistics equipment. In the conditions of a military operation, the loading and unloading process is supported by the national logistics subdivisions (National Support Element) and multinational units (e.g. Joint Logistics Support Group).



S/APOE/D: Surface/Aerial Port of Embarkation/Debarkation
ALSS: Adv Log Supt Site
FLS: Fwd Log Site
TLB: Theater Log Base
NSE: Natl Supt Element
JLSA: Joint Log Supt Area
CSC: Convoy Supt Cntr
DOB: Depl Oper Base
LSA: Log Supt Area

Figure 1 Theater level NATO logistics

Source: AJP-4.6 Allied Joint Logistics Doctrine for Joint Logistic Support Group, NATO Standardisation Agency 2014.

With a purpose of proper preparation of the armed forces of NATO states for the threats of the modern world, the members of the Alliance decided to determine the needs to be fulfilled to be adequately secured. These actions take place cyclically (every two years), within the Defense Requirements Review (DRR). On this basis, NATO Armed Forces' Objectives and sets of tasks were defined, which are updated in subsequent editions and undertaken by individual countries. The most important documents on the sphere of transport and movement of troops include:

- E 4174 - Requirements for strategic transport - Air and Maritime Transport;

- E 4155 - Air transport in the theatre of operations;
- E 0035 - Mobile safety forces of various readiness.

Based on the conducted thorough analysis of conclusions from previous operations and taking into account the initiatives from other member states of the Alliance, the so-called Long Term Capability Requirements (LTCRs) that future armed forces should be characterized with have been identified. The most significant requirements in scope of efficient transfer of troops include the following needs [9]:

1) Ability to conduct and support multinational expeditionary operations outside one's territory, without aid from the host state, including among others the following elements:

- NATO offshore platform - specifying deployability of a troops package adopting amphibious platforms for maritime transport and tactical airlift. Such a mode of action must be verified in terms of its possible use throughout the whole operation, not only during its initial phase;
- strategic transfer, both by air and by seas as a basic NATO capability that changes the concept of expedition into reality;
- operations adopting airlift as a means of relocation of the troops and providing supplies during an expeditionary operation.

2) Ability to change military groupings and respond in a fast and effective way in the case of unforseen developments. It includes loading and unloading of troops, where centralization of air and sea ports of embarkation leads to better exploitation of the available resources, and the number of European ports of embarkation will be brought down to a minimum. Limitation of the number of ports will allow some financial savings related to the package loading of the troops and their safeguarding, and will decrease the risk of an unexpected strike from the opponent..

3. SCALE OF THE ANALYZED PHENOMENON

Maritime transport in the Polish Armed forces is carried out using, among other things, the vessels of the Polish Navy. However, it must be stressed that they are limited. These are five 767 Lublin vessels and a Polish vessel "Kontradmirał Xawery Czernicki". The Lublin vessels can take e.g. nine T-72 tanks or seventeen medium-load trucks and 135 soldiers with individual equipment [2]. On the other hand, the Polish vessel "Kontradmirał Xawery Czernicki" is capable of transporting up to 1400 soldiers with equipment, or ten 20ft containers of a total weight of 150 tons, or six Star 266 trucks (in the back part of the board) and 4 containers [2]. It must also be accepted that these vessels cannot be used for strategic transport. This results from limited capacity to carry out transport operations, including: maximum range of 4,000 nautical miles, while according to NATO standards, Poland should be capable of transporting a single brigade or two brigade battle groups composed of about 5000 soldiers [2]. Table 1 presents transport capacity of the Polish Navy ships.

Table 1 Transport capacity of the Polish Navy ships

Type of the ship	Number	Age of the ship (years)	Speed (knots)	Range of the ship (nautical miles)	Transport capacity	
					Carriage of people	Carriage of cargo (tons)
Minelayer-landing ship 767 Lublin	5	30	16	7850	125	400
Logistical support vessel* Polish ship Kontradmirał Xawery CZERNICKI	1	17**	14	1400	140	150
In total	6				765	2150

Source: Biernikowicz W., Outsourcing usług transportowych w Siłach Zbrojnych RP, Wyższa Szkoła Oficerska Wojsk Lądowych, Wrocław, 2017, p. 192.

Road transport has the greatest share in military carriage, and it results from the features of this branch of transport, including flexibility, availability, speed, punctuality. It seems obvious that maritime transport will be used for strategic carriage, and the chief domain will be to safeguard the functioning of armies which implement tasks outside the country, in the scope of Poland's allied commitments within NATO and EU. Table 2 presents the structure of military transport in particular transport branches between 2014 and 2018.

Table 2 Structure of military transport presented in branches between 2014 and 2018

Type of transport	2014	2015	2016	2017	2018	Notes
Maritime transport	7	5	1	2	0	
Air transport	239	170	224	281	231	Flights completed including SALIS and SAC
Rail transport	122	187	198	411	314	Operational transports and supplies
Road transport*	8618	9440	10225	11835	12852	* Based on the number of "road use permits" issued

Source: Jalowiec T., Mitkow S., Radomyski A., Smal T., Teska J., Woźniak R. (eds.): System logistyczny SZ RP. Raport 2019, ASzWoj, Warszawa, 2019, p. 131.

An example of using civil ships for the transportation of the Polish military equipment is the transfer of heavy equipment and containers with supplies to Polish military contingents abroad. Fig. 1 presents organization of equipment transfer for the Polish military contingent for Chad. The seagoing ship set off from the port of Szczecin (Poland) to the port of Douala (Cameroon) covering 7500 miles.

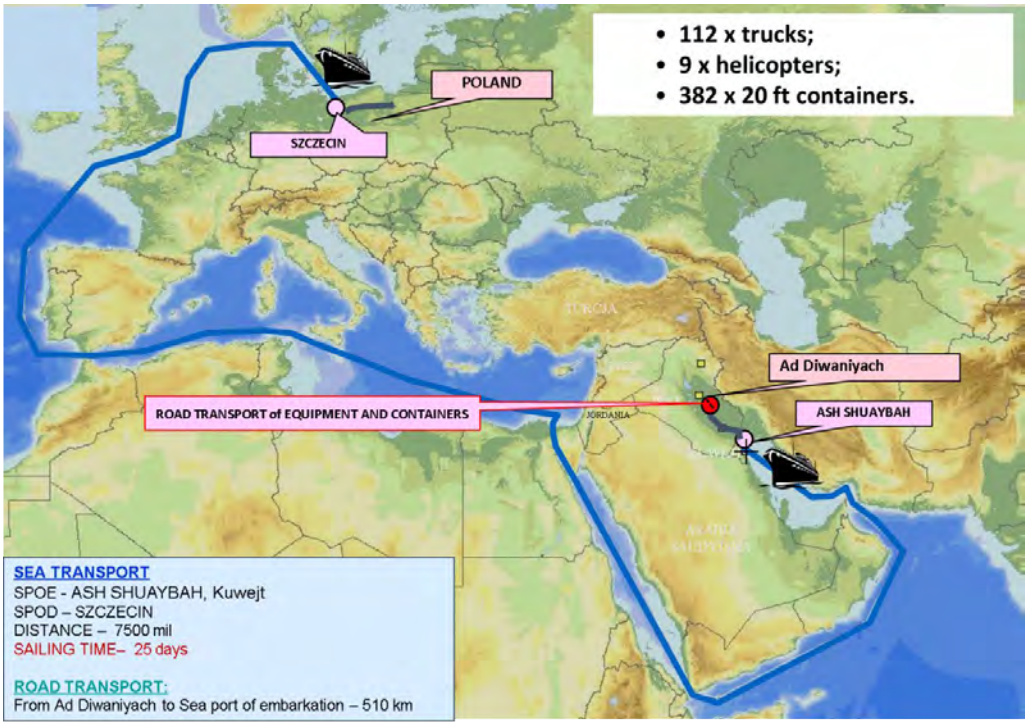


Figure 2 Sea transport of military equipment from Chad to Poland

Source: Materials from Operational Command of Polish Armed Forces.

Similarly, during the withdrawal of the Polish military contingent for Chad from Libya to Szczecin in 2008, three chartered vessels transported 556 containers and 93 units of equipment, mainly vehicles (the cost was about EUR 1.7 mln). A year later a vessel was chartered to transport 17 containers and 35 units of equipment for the Polish military contingent UNIFIL (cost: EUR 470k). Civil ships for military transport were acquired for the needs of virtually all operations performed outside Europe (Congo, Chad, Iraq, Afghanistan) [2].

In the case of large contingents, the maritime transport is used not only at the beginning or completion of the mission but also within its course. During the operations of the Polish military contingent for Iraq, there were sealifts implemented apart from the airlifts, most of the time because of withdrawal of the surplus equipment as a result of structural changes in the contingent. Therefore, in the subsequent years the following transports were implemented:

- 2004: 1 transport to Iraq - 142.4 tons of equipment and materials, including 18 equipment units and 23 containers;
- 2005: 2 transports to the country - 3942.4 tons of equipment and materials, including: 323 equipment units and 204 containers;
- 2006: 2 transports to Iraq - 148.8 tons of equipment and materials, including: 13 equipment units (7 helicopters) and 11 containers;
- 3 transports to Poland - 2520.1 tons of equipment and materials, including: 228 equipment units (11 helicopters) and 119 containers;
- 2007: 3 transports to Poland - 1787 tons of equipment and materials, including: 226 equipment units (5 helicopters) and 102 containers;
- 2008: 2 transports to Poland - 2198 tons of equipment and materials, including: 182 equipment units (8 helicopters) and 442 containers.

4. DIRECTIONS FOR DEVELOPMENT

Nowadays, no country, apart from the largest ones, is capable of meeting its strategic transport needs on its own. At the same time, the requirements of today's global world and participation in allied NATO operations make the Polish Armed Forces to move large amounts of persons and equipment over long distances [2].

An example of allied cooperation in the scope of strategic maritime transport for the needs of the armed forces is a program known as the Athens Multinational Shipping Coordination Centre (AMSCC). It allows for faster acquisition of civil transport resources by free advice and agency in the access to those resources. The tender procedure and selection of a carrier takes about 45 days in the case of AMSCC. Poland, based on the Memorandum of Understanding between the Minister of Defense of the Republic of Poland and the Minister of National Defense of the Hellenic Republic on cooperation with the Athens Multinational Shipping Coordination Centre and the resulting Technical Agreement, has been a member of this programme since 1 March 2008. In the same year, the Accession Note on joining another initiative, which is the Movement Coordination Centre Europe (MCCE), was also signed. It was established in 2007 and it brings together 21 countries (including those outside NATO, e.g. Sweden). It was created by combining the Maritime Transport Coordination Centre and the European Air Transport Centre. Similarly as in the case of AMSCC, MCEE does not possess any means of transport, and its role is limited to support in planning the transport and acquiring adequate resources. Each country being a member of the program, including Poland, is obliged to pay a membership fee [2]. The Polish vessels and ships used for transportation of the Polish Armed Forces remain under the national control throughout the entire transportation process. Foreign vessels and ships used for the transportation of the Polish Armed Forces remain under the control of national and allied commands determined in the understandings or agreements concerning their use [2].

Poland must acquire the capability of strategic transport. On 18 December 2018, 2nd Regional Logistics Base informed about concluding agreements for provision of civil maritime transport for the Armed Forces. The tender for the provision of the service was announced in February 2018. The Polish Army looked for the maritime transport service provider within the European Union and outside the Community. The contract is to be valid for a period of seven years. Eventually, two bidders joined the contest for the above contract, and one of them was selected. Kuehne + Nagel Sp. z o.o. together with DSV Air&Sea Sp. z o.o. became the service providers for both tasks. In each task, the contract has a total and maximum value of PLN 512 mln, excluding VAT. Under the contract, the army sought for a service provider capable of transporting rolling loads on a vessel with a loading line of max. 5000 meters, over a distance of 6000 nautical miles and 10000 nautical miles, as well as containers over the same distances. Furthermore, the service provider is to provide social space and accommodation of a convoy of max. 10 soldiers on-board. In recent months the maritime transport was used to, among other things, transfer the equipment to Norway where the Polish Army took part in the Trident Juncture maneuver [4].

Under the contract, the army can count on a series of services related to maritime transport. The army has the right to [5]

- transport of cargo with a total loading line (LMs) up to 5000 m within 45 days of receiving the demand
- one transport of cargo in the amount of up to 1000 20ft containers (20 tonnes gross)
- one transport of cargo in the amount of from 1001 to 2000 20ft containers (20 tonnes gross)
- one transport of cargo in the amount of from 2001 to 3000 20ft containers (20 tonnes gross)
- one transport of cargo in the amount of from 3001 to 4250 20ft containers (20 tonnes gross)
- accommodation and social facilities on each ship for a convoy of the cargo.

The first and the second task (carriage within and outside EU) differs with the distance of operations. The first one consists in the carriage at the max. distance of 6000 nautical miles, and the second one is up to 10000 nautical miles. It will work based on a special contract made according to the specification of the tender announced in February 2018. The army used to transport its equipment by sea thanks to cooperation with American companies. It made the army dependent on external suppliers who imposed large amounts of money for the service. Now the army will invest in domestic transport, and it will become one of the factors for development of the maritime transport in Poland. Of course there are some people asking why it was not invested in an operational support vessel which would made the army completely independent from external influences [5]. Such a solution would provide the army with more room for action not only in the sector of own transport, but it would certainly improve the strength of the Polish maritime transport. The adopted solution also has a lot of advantages. The greatest is certainly the money that the military is willing to invest in the sector. However, we will need to wait to see the results, and the unstable geopolitical situation can change the army's plans for later years. It is therefore worth observing the situation. The only certain thing is that the container with military equipment will soon go into international waters [5].

It should be expected that regarding the nature of the demanded capabilities of armed forces which result directly from the requirements of the international security and concluded agreements, the states will be sending their troops abroad. Participation in military operations, humanitarian aid in case of natural disasters and maneuvers organized abroad will require transfers of military equipment over long distances. Functioning in the conditions of seeking economic solutions, it seems that maritime transport will be often used regarding the capability of mass carriage, transport safety and relatively low prices per unit of equipment. Therefore, the development of the armed forces' capabilities in the scope of strategic maritime transport is justified.

5. CONCLUSION

The article was intended to identify the scale of the maritime transport phenomenon in the Polish Armed Forces over the last decade, and to indicate the developmental directions employed during military operations. The conducted analyses suggest that the maritime transport was used multiple times for the transfer of heavy equipment and supplies for troops carrying out tasks abroad allowing to obtain sizable savings when compared to the alternative air transport. Due to the lack of access to the sea, transport to sea ports took place by rail, road or transport aircrafts.

Poland, similarly to other European Union member states must acquire capabilities of strategic transport. The way to do this is to conclude international agreements, implement common allied programs and make civil law contracts on the commercial market. The first solution, although not always the least expensive one, seems much more certain. It would be advisable, but not necessary, for Poland to become more involved in international initiatives for strategic transport.

REFERENCES

[1] AJP-4.6 Allied Joint Logistics Doctrine for Joint Logistic Support Group, NATO Standardisation Agency, 2014.
[2] Barcik J., Czech P.: Umowy i programy międzynarodowe z zakresu zdolności transportu strategicznego, Logistyka, 2014, No 2, pp. 364-368.
[3] Biernikowicz W., Outsourcing usług transportowych w Siłach Zbrojnych RP, Wyższa Szkoła Oficerska Wojsk Lądowych, Wrocław, 2017, p. 192.
[4] http://zbiam.pl/1-mld-zlotych-na-usluge-transportu-morskiego/ - 12.06.2019.
[5] https://www.seaoo.com/blog/wojsko-potega-w-transporcie/
[6] Instrukcja o przewozach wojsk oraz uzbrojenia ı sprzętu wojskowego transportem morskim (DD/4.4.3), MON-SG WP, Warszawa, 2006, pp. 10-11.
[7] Jalowiec T., Mitkow S., Radomyski A., Smal T., Teska J., Woźniak R. (eds.): System logistyczny SZ RP. Raport 2019, ASzWoj, Warszawa, 2019, p. 131.
[8] Materials from Operational Command of Polish Armed Forces.
[9] Smal T., Biernikowicz W., Milewski R.: Problemy transportu wojskowego w operacjach poza granicami kraju, Zeszyty Naukowe WSO WL, 2010, Vol. 158, No 4, pp. 256-257.
[10] Transport i ruch wojsk Sił Zbrojnych Rzeczypospolitej Polskiej (DD/4.4(B)), MON-CDiSzSZ, Bydgoszcz, 2013, pp. 63-70.

WATER TUNNEL MEASUREMENT STAND FOR RESEARCH ON UNDULATING PROPULSION

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Summary

Recently, development of different constructions of Biomimetic Underwater Vehicles (BUVs) may be observed. These vehicles largely imitate underwater creatures in their appearance, as well as in their way of propulsion and motion. BUVs are driven by the set of artificial fins. This kind of propulsion is not as well known as conventional propulsion used in Unmanned Underwater Vehicles (UUVs) consisting the screw propellers. For this reason, research on an undulating propulsion system is significant and interesting, in particular taking into consideration tools and methods to improve its energy efficiency. This paper presents the measurement stand for research on a physical model of the undulating propulsion. The stand was designed and built in the Institute of Electrical Engineering and Automatics in Polish Naval Academy. The research is aimed at increasing the capabilities of speed and acceleration achieved by the BUV. Designed test stand allows us to examine the influence of construction parameters of a single fin, e.g its shape on an energy consumption and a generated thrust. The measurements of the generated propulsion force is to be carried out using precise strain gauges mounted on the both sides water tunnel. At the beginning of this paper, the introduction to the research with the literature analysis is inserted. Then, the design and description of the measurement stand were presented. In the next section, the calibration of the measuring apparatus and the acceptable measurement errors are depicted. Next, the preliminary results of the research using the stand are presented. At the end of the paper, the conclusions and foreseen research are included.

Keywords: biomimetic underwater vehicles, undulating propulsion, thrust measurement

1. INTRODUCTION

In the recent years, there has been a dynamic development of underwater robotics. Unmanned Underwater Vehicle (UUVs) are becoming more and more popular in the marine environment. They are used in a wide range in the maritime industry, as well as for military, research or scientific tasks. Above all, they are used to inspect underwater technical infrastructure, perform construction or renovation works [1][8]. The group of the most innovative structures in this field are autonomous Biomimetic Underwater Vehicles (BUVs) [2][12]. These vehicles imitate underwater organisms not only in terms of their appearance, but also in terms of construction and in their way of motion [18]. Most research is conducted on fish-like vehicles with undulating propulsion. These types of vehicles have military-relevant characteristics: they have a propulsion system that is more energy-efficient and quieter than a classical propulsion system based on screw propellers, whose energy efficiency is limited to 70% and 20% less efficiency than an undulating propulsion [9]. In addition, the large similarity to real inhabitants of the underwater environment influences on greater secrecy and potentially greater range of action [16].

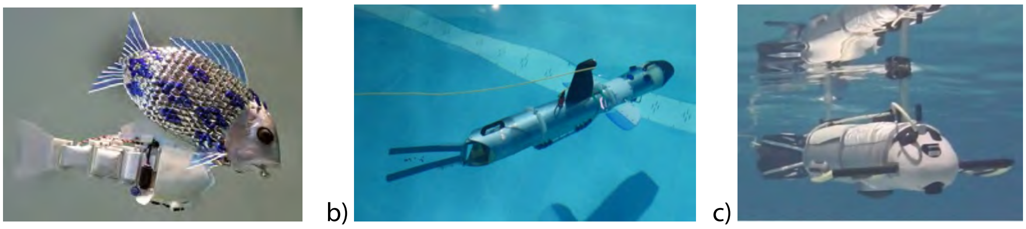


Figure 1 Biomimetic underwater vehicles a) G9 b) BUV No. 2 c) Cyber-Seal

Source: [11], Own study AMW

There are two main methods of mapping fish movement in the design of fish robots. In the first method, a flexible tail fin is used, connected to a rigid hull by means of a movable axle. The second method is based on the synchronized operation of many mechanical connections, in order to imitate the same tail movement that can be observed in a real fish. Many of the links that are needed to accurately reproduce the behavior of the fish make the mathematical model of the robot-fish and control technique more complicated. In addition, increasing the number of tail segments increases the likelihood of water leaking from the connection areas, which can lead to the destruction of sensitive electronic components inside. In addition, the costs of production and service increase considering the swarm of artificial fish robots i considered. For this reason, it was assumed that fish movement should be reproduced by a one-piece flexible fin with a motor shaft mounted on its front edge.

In contrast to screw or cycloidal propellers, the fin is made from elastic material. The mathematical model of the fin containing a stiffness of the fin as function of the motion velocity will have the form of a nonlinear differential equation. Only experimental investigations may allow to obtain initial conditions for the numerical simulations, the BUVs using the flexible fins have the ability to reproduce complex movements of fish. For this reason, the research on the influence of the parameters of different shapes of the elastic tail fin, e.g. its shape and dimensions on the speed and efficiency of the undulating propulsion drive is needed. The deep analysis of selection of Optimal shape and motion of undulatory swimming is including in [21]. Taking into consideration research above-mentioned it can be concluded that special measurement stand in the form of water tunnel is needed for selection of proper paameters of the undulating propulsion.

The aim of the paper is to present the process of designing, implementation and first results of work the measurement stand used for selection of proper flexible fin. The stand enables testing of various types and shapes of undulating propulsion with the possibility of changing the speed of the fluid in a set positive flow.

2. OVERVIEW OF MEASURING STANDS TO TEST THE UNDULATING PROPULSION

Research on undulating propulsion is currently carried out at many leading research centers in Europe, the USA and Asia [3][4][13][15][18][22]. The following are exemplary test stands where experiments in the range of generated thrust force for various tail fin variants and control parameters are carried out.

2.1. Measuring stand at the National University of Seoul, South Korea

The publication [15] presents the results of research on the thrust force for various variants of the shape of the tail fin made of materials with different stiffness. In order to measure thrust, the tested fin was placed in a measuring stand (Figure 2), which was equipped with a yoke mechanism that puts the tail fin in an oscillating movement, imitating the movement of puffer fish. The installed strain gauges perform the measurement, allowing to determine the value of the thrust force for different variants of the control parameters.

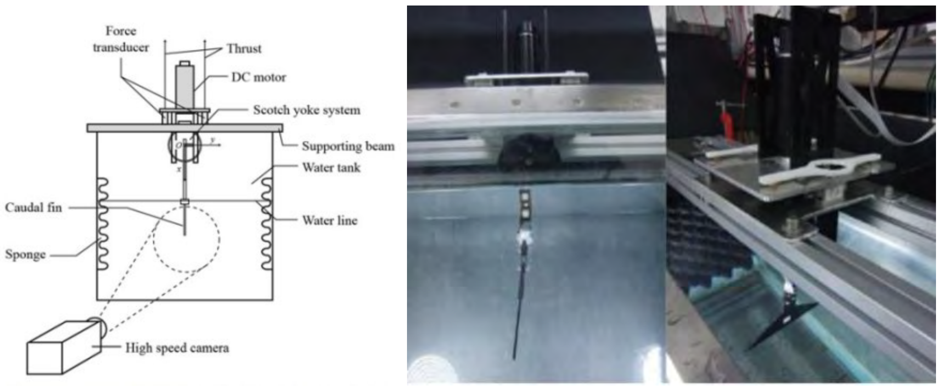


Figure 2 Measuring stand

Source: [15]

2.2. Measuring station at Beihang University, China

The publication [11] presents experimental investigations in the scope of measurement of thrust force and efficiency of the propulsion module, made of three parts, ending with a flexible tail fin. The thrust force measurement was carried out on a measurement stand (Figure 3) for various control variants. The stand has a towing system powered by an AC motor with a power of 4000 [W], the ability to tow to a distance of 7.5 [m] with a precision of 0.1 [mm]. Under the towing system there is a 7.8 × 1.2 × 1.1 [m] water tank to allow the biomimetic vehicle to move smoothly from the boundary layer. The thrust of the vehicle's drive is measured using the Kislter 9254 C piezoelectric force transducer, which is mounted vertically above the vehicle.

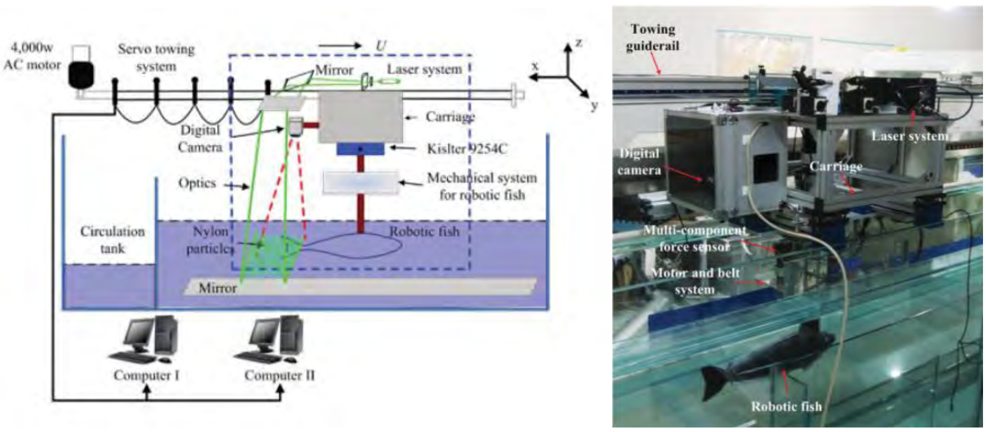


Figure 3 Measuring stand

Source: [11]

2.3. Measuring stand at the Cracow University of Technology, Poland

In his doctoral thesis M. Malec [13] presents the *Laboratory of underwater mobile robots with undulating propulsion*, which includes, among others: two stations for measuring thrust, position for measuring the average value of swimming speed, a station for video analysis of vehicle movement trajectory, test bed for submarining subsystems using a ballast tank, pressure chamber for testing vehicle hulls and an acrylic pool for testing robots in the aquatic environment.

The basic element is the acrylic pool that allows check the underwater vehicle for buoyancy and trim. The stand also enables the implementation of measurements of thrust, tests of biomimetic vehicle control algorithms and registration of the trajectory of motion using a vision system.

The stand intended for the tests of the thrust force of the robot "Śledzik" (Figure 4) allows suspend the tested vehicle. The design allows it to be extended to match the length of the vehicle being tested. A strain gauge KAP-S50N with a measuring range of 50[N], resolution 0.001[N] and sampling frequency up to 400[Hz] connected to the BD342 transducer was attached to the frame.

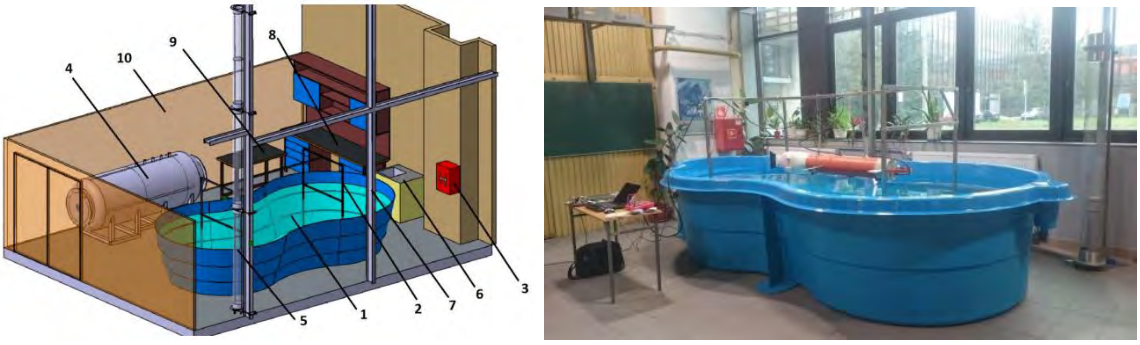


Figure 4 Laboratory of underwater mobile robots with undulating propulsion; 1 – acrylic pool, 2 – position for measurement of draft force, 3 – fire hydrant, 4 – pressure chamber, 5 – station for testing subsystems, 6 – sanitary station, 7 – structural elements of the hall, 8 – test stand with measuring devices, 9 – mobile assembly station, 10 – side wall construction element.

Source: [13]

2.4. Measuring stand in the Laboratory of Biological Systems Analysis, USA

Scientific team in their research [4][5] focuses on how to more accurately reproduce the tail fin of the fish, transferring it to the BUV. It accomplishes this by constructing a robotic model with six individually controlled fins that enable detailed control of the fin's motion. The model is placed in a special frame immersed in a water tank. The frame includes rotary servomotors, a control board and fastening mechanisms for the trolley system. The tensioners (thin white polyethylene thread) placed above the water level enable precise tension regulation in each of the radii of the fin. They are run from servos, through the model to the rays of the fin.

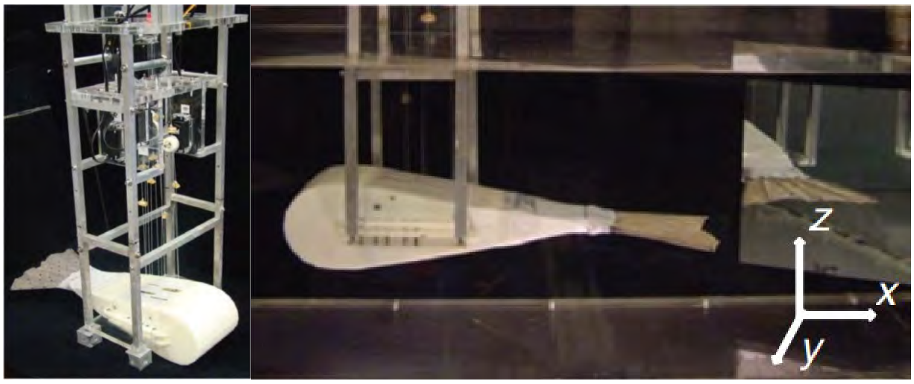


Figure 5 Measuring stand

Source: [4][5]

2.5. Measuring stand at the University of Firat, Turkey

An example of tests necessary to determine vehicle motion parameters is presented in the paper [14] showing the influence of control parameters of the tail fin propulsion system on the trajectory of the biomimetic vehicle movement. Using the measuring stand (Figure 6), the swimming speed and radius of circulation of the robot equipped with a two-unit drive module ended with a flexible tail fin was measured. The experimental results developed constitute a component of the semi-autonomic swimming system.

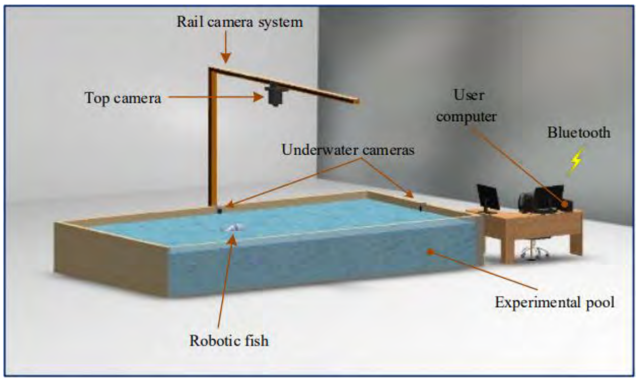


Figure 6 Measuring stand

Source: [14]

3. MEASUREMENT STAND OF WATER TUNNEL

Conducted at the Institute of Electrical Enginnering and Automatics research on underwater vehicles are mainly focused on the development of control, communication and navigation systems. A parallel problem requiring investigation is an undulating propulsion that imitate operation of aquatic living organisms. Tools and methods are being sought to improve the energy efficiency of the undulating propulsion, and the finally to increase velocity and acceleration achieved by the BUV. The experimental method was selected for the research because of the low accuracy of the computer simulation of the complex phenomenon, which is the mutual interaction of a solid body of BUV and a fluid. Another factor determining the choice of the method in the form of an experiment is the very large computational power necessary to determine the interaction between a fluid and a solid body.

3.1. Design assumptions

It was assumed that water is considered as an incompressible fluid, with constant temperature and density, however, the viscosity and density of the fluid can be changed depending on the needs. The selection of markers for fluid flow must be carried out in such a way that the fluid parameters do not be changed locally and globally. It follows that the markers should have neutral buoyancy. The area of fluid subjected to analysis should not be disturbed by the research equipment, therefore it was assumed to use a laser to highlight the examined fluid layer. The internal surfaces of the water tunnel should have a low roughness, similar to smooth wires.

3.1.1. Determination of the flow character

The flow of the real (viscous) liquid in the pipes is forced by the pressure difference. It is always associated with energy losses that increase the total energy needed to transport liquid [10][20]. In engineering practice, a flow criterion is assumed for circular section pipelines completely filled with liquid in accordance with PN-76 / M34034 - principles for calculating pressure losses [23]. Since the undulating propulsion is dedicated to autonomous underwater vehicle, the open water channel will be analyzed. The following criterion was assumed for flow [19]:

- Re < 2300 – laminar flow (ordered, stratified, stabilized movement),
- 2300 < Re < 4000 – transitional flow (partly turbulent, unstabilized),
- Re > 4000 – turbulent flow (turbulent, stabilized traffic).

The Reynolds number is a criterion number (probability) that determines the nature of the fluid flow in accordance with the relationship of the inertial force ratio ($\frac{\rho U^2}{L}$) to viscosity forces $\frac{\mu U}{L^2}$ [20]:

$$Re = \frac{\frac{\rho U^2}{D}}{\frac{\mu U}{D^2}} = \frac{\rho U D}{\mu} = \frac{UD}{\gamma} \tag{1}$$

Where:

U - average flow rate [m/s];
D - characteristic dimension, e.g.: diameter of the pipe [m] for a circular section. For other cross-sections, the characteristic dimension is defined as the ratio of four surface areas to the perimeter;
$\gamma -$ coefficient of kinematic viscosity of the fluid under flow conditions, $\gamma = \gamma(T)$ $[\frac{m^2}{s}]$;
μ – dynamic viscosity coefficient;

The relationship between the coefficient of dynamic viscosity μ and kinematic γ is given by the formula:

$$\mu = \rho\gamma \tag{2}$$

Where:
ρ – is the density of the fluid.

To determine the energy balance of a liquid flowing in a water tunnel, one should use the mass conservation equation (flow continuity equation) [7]:

$$Q = AU \tag{3}$$

Q – volume flow (volumetric flow rate)$[\frac{m^3}{s}]$,
A – cross-sectional area$[m^2]$;
U – average flow rate $[\frac{m}{s}]$.

The distribution of laminar flow velocity in a circular section pipeline is expressed by the following dependence:

$$U(r) = U_{max}(1 - \left(\frac{r}{R}\right)^2 \quad (4)$$

However, the maximum velocity for laminar flow is determined by the dependence:

$$U_{max} = \frac{\Delta p R^2}{4\mu L} \quad (5)$$

U_{max} – maximum speed in a laminar flow [m/s];
L – length of the pipeline section [m];
Δp – pressure drop over the length of the pipeline L [Pa];
R – pipeline radius [m];
r – distance of the axis from the pipeline [m];

The average flow speed is half the maximum speed.

For turbulent flow, the velocity distribution can be determined from the dependence of:

$$U(r) = U_{max}(1 - \left(\frac{r}{R}\right)^{\frac{1}{n}} \quad (6)$$

Where:

n – is a coefficient linearly dependent on the Reynolds number [-].
The average flow velocity in turbulent motion is approximately equal to the maximum speed.

3.1.2. Distribution of flow velocity in the hydrometric section

The hydrometric cross-section is the cross section of the open channel (channel with a free surface) selected for measurement, straight line, regular, perpendicular to the direction of a water flow. The velocity distribution in the hydrometric vertical is not even. The lowest flow velocities occur at the bottom of the channel. The velocity increases towards the water surface reaching the highest values in the near-surface zone. The maximum speed occurs not at the level of the water surface, and slightly below, due to the resistance occurring at the interface of the water-air center.

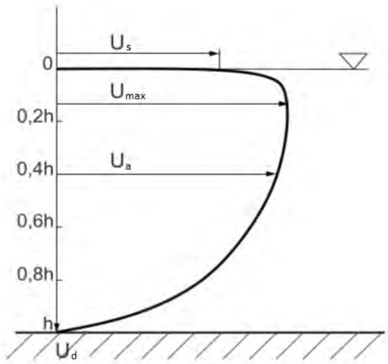


Figure 7 Speed profile in the hydrometric vertical surface

Source: [7]

The average speed in the hydrometric vertical can be determined by the dependence:

$$U_a = \frac{\int_0^h U dh}{\mathrm{h}} \quad (7)$$

In practice the average speed can be determined by means of the formulas depending on the selected, short measurement method. Measurements are used at a depth of 0.4 total depth or simultaneously at a depth of 0.2 and 0.8 while averaging both values.

In a steady-state motion, flow parameters along the channel are unchanged over time. Such movement occurs in open channels with homogeneous surface roughness of the bottom and walls, identical cross-sections, uniform bottom drop, constant flow rate and constant filling.

In a steady motion, the water surface is parallel to the bottom. The piezometric line (static pressure line), the total pressure line and the energy line runs parallel to the water surface. In the water motion in open channels some of the mechanical energy of the stream is used to overcome the flow resistance.

3.1.3. Flow resistance in pipelines

The coefficient of resistance can be determined depending on the nature of the flow [7]:

For laminar flow the resistance coefficient is calculated according to the next formula:

$$\lambda = \frac{a}{Re} \tag{8}$$

Where:

For pipelines: circular a = 64; square a = 57; while for rectangular pipelines with the ratio of sides 1: 2 a = 59.

For the transient and turbulent flow (2000 <Re <105), the so-called Blasius pattern:

$$\lambda = \frac{0{,}3164}{\sqrt[4]{Re}} \tag{9}$$

For the values of Reynolds numbers above the 2000, the Nikuradse formula is used:

$$\lambda = 0{,}0032 + \frac{0{,}221}{Re^{0{,}237}} \tag{10}$$

The losses of the actual fluid pressure due to its internal friction can be calculated from the Darcy-Weisbach formula:

$$\Delta p = \lambda \, \frac{L\rho U}{D_z \, 2} \tag{11}$$

Where:

D_z – is the equivalent diameter for non-circular pipelines.

3.2. Construction design

The first stage of the water tunnel implementation was the construction design in the Inventor environment. The use of computer-aided design enabled the initial verification of errors and construction decisions, as well as the analysis of the nature of the flow. Then, the construction materials were selected, after which the construction of the physical model of the water tunnel began.

The water tunnel has been designed in the shape of a rectangle with one beveled corner in order to limit the turbulence of the flow. The length of the side walls of the fairway with the value of 1500 [mm] was assumed. The three corners have a 90 [deg] angle. One corner was divided into two curves of the track with an angle of 45[deg].

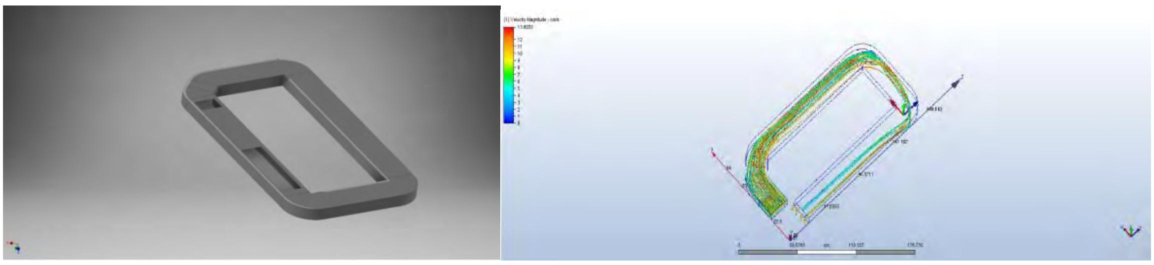


Figure 8 Water tunnel project - view in axionometric projection and the use of Inventor Computational Fluid Dynamic to analyze the nature of the flow

Source: Own study AMW

3.3. Construction of the water tunnel

The water tunnel was made of polyethylene panels, with the following dimensions: 0.09 [m] height, 0.22 [m] width, 0.0198 [m^2] cross-sectional area. Different types of flexible fins can be attached to the servomechanism (Dynamixel AX-12 +), which is fixed to a transparent polycarbonate plate mounted on ball bearings above the water surface. Measurements of the generated thrust are made by means of two precision strain gauges installed differential on both sides of the water tunnel. Forced fluid flow is carried out by means of a pump with the controlled fluid speed. The non-invasive method was used to measure the velocity of the fluid using an ultrasonic flowmeter. The view and description of the measurement station are shown below:

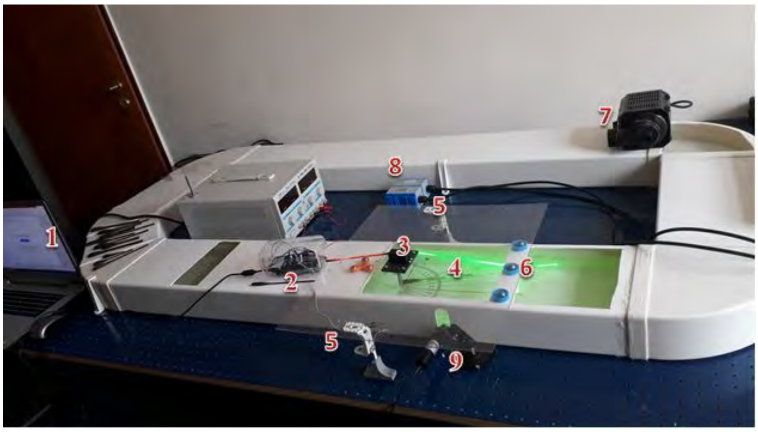


Figure 9 Measurement stand; 1 – computer, 2 – microconrtroller, 3 – servomechanism, 4 – tested fin, 5 – strain gauges, 6 – ball bearings, 7 – water pump, 8 – flowmeter, 9 – laser

Source: Own study AMW

A pump with an output of 10,000 liters / hour was adopted for forced flow, which after conversion gives the value: 2,78 [$\frac{l}{s}$] (liters per second), ie. 0,00278 [$\frac{m^3}{s}$].

Apart from the energy losses, the water velocity in the track will be equal:

$$U = \frac{Q}{A} = \frac{2{,}78*10^{-3}}{19.8*10^{-3}} = 0{,}14\ [\frac{m}{s}] \quad (12)$$

The volume flow rate is:

$$Q = 0{,}0198\ [m^2] * 1\ [\frac{m}{s}] = 0.0198\ [\frac{m^3}{s}] \quad (13)$$

After taking into account the energy losses, the water velocity in the track will be around:

$$U = 0{,}1\ [\frac{m}{s}] \quad (14)$$

However, the volume flow rate:

$$Q = 0{,}0198\ [m^2] * 0.1\ [\frac{m}{s}] = 0.00198\ [\frac{m^3}{s}] =\sim 2*10^{-3}\ [\frac{m^3}{s}] \quad (15)$$

Using the formula (1), where the characteristic dimension (equivalent diameter) is:

$$D_z = \frac{4P}{Obw} = \frac{4*0.09*0.22}{2*0.09+2*0{,}22} = \frac{0.0792}{0.62} = 0{,}1277 \quad (16)$$

The Reynolds number is:

$$Re = \frac{1000*0.1*0.1277}{1.003*10^{-3}} = 12770 \quad (17)$$

For the speed U = 0.01 m/s, the Reynolds number will be: Re = 1277 [-], which ensures flow laminarity with a large reserve of pump volume.

To determine the water flow rate, the NFM300M flowmeter was selected, which works using the ultrasonic method. It measures the signal transition time between two sensors mounted on the measuring path with a resolution of 100 [ps]. The ultrasonic method guarantees non-invasive measurement of the flow velocity of the liquid. The measuring sensors are located on the outside of the measuring path. The flow meter used has a measurement accuracy of less than 1% of the measured value.

A 100 [mW] linear laser was selected to determine the plane of the analysis of the fin and fluid impact. The use of several lasers with different heights will enable simultaneous analysis of several planes. For this purpose, filters should be programmed, for each plane separately.

To illustrate the fluid area in order to determine the nature of the flow in the designated area of interaction of the fin with the liquid, the following markers were analyzed:

- In the form of guards from potassium permanganate.
- Silver particles with neutral buoyancy;
- Hydrogen molecules in the form of a large number of small bubbles.

The motion of the tested fin is carried out by the Dynamixel Ax-12A servo. Its produces torque 1.5 [Nm] with 12 [V] power supply. The speed without loading is 59 [rpm] with 12 [V] power supply. The servomechanism can be supplied with a voltage of 9 to 12 [V]. Recommended power voltage is 11.1 [V]. AX-12A is equipped with a communication protocol: half duplex asynchronous serial communication, which allows you to receive feedback from the servomechanism, including servo position. The communication speed range is from 7343 [bps] to even 1 [Mbps].

3.4. Thrust measurement

Figure 10 presents two a schemes of the system for measurement of the force in the longitudinal axis of symmetry *X* and the moment of force relative to the vertical axis of symmetry *N* [6] generated by the undulating propulsion based on signals obtained from two strain gauges located on both sides of the water tunel measuring forces F_1 and F_2. The forces generated by the undulating propulsion cause the plate with the servo and attached strain gauges to move. On the other hand, strain gauges are attached to a stationary floor. The motion of the plate with servomechanism with respect to the water tunnel is carried out using ball bearings.

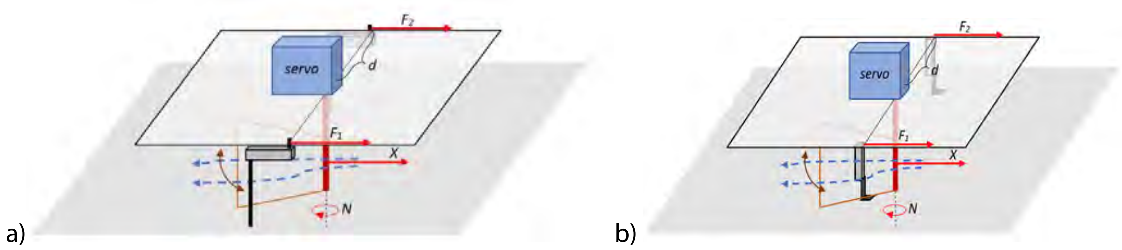


Figure 10 Measurement of force X and moment of force N based on of forces F_1 and F_2 obtained from strain gauges, acting on a) compression and stretching b) shearing

Source: Own study AMW

An important element of the sand are strain gauges. Depending on the manufacturing technology, resulting primarily from the measured range of forces, strain gauges can act on compression and stretching or shearing. In both cases the strain gauges must be fixed in a different way: Figure 10 a) – for compression and tension, Figure 10 b) – for shear force. During the research presented in the paper second approach was accepted (Figure 10 b).

It is noteworthy that the measurement of force in the case of strain gauges is an indirect measurement, i.e. a tensometer (*Latin tensus - tight, gram metréô - measure*) is a sensor used to measure stress. In practice, the tensometric measurement depends on in measurement of the strain and calculation on of the stress based on the adopted physical relationship (eg Hooke's law). In addition to the force measurement, strain gauges are also indirectly used to measure other non-electrical quantities such as pressure, acceleration, and mass. Most often resistance strain gauges are used, changing their resistance with a change in dimensions. Resistance changes are very small, therefore for measuring the above changes are usually used Wheatstone bridges.

The presented measurement system was verified during previous tests on the physical model of the tether undulating propulsion [18]. The use of two strain gauges enables the measurement of two forces F_1 and F_2, which in turn makes it possible to determine the force in the longitudinal axis of symmetry *X* and moment of force in relation to the vertical axis of symmetry *N*. The force *X* is the sum of forces obtained from two strain gauges F_1 and F_2. However, the moment of force *N* is the product result of the difference of forces F_1 and F_2 and of the arm of the force, i.e. the distance d (Figure 10).

Based on previous experiments [17], the Arduino microprocessor platform was used with an additional signal amplification system derived from Wheatstone strain gauges (Figure 11). The strain gauge has the following:

- sensor with Wheatstone bridge,
- rated output: 600 µV / V,
- supply voltage: 3 -10 V DC.

Figure 11 Tensometer with Wheatstone bridge for mass measurement up to 100 [g]

Source: Own study AMW

At an external power supply connected to tensometer 3.3 [V], a rated output voltage of 1.98 [mV] is obtained. The signal obtained from the extensometer must therefore be amplified to obtain the appropriate signal that can be sent to the ADC converter. For this purpose, a 2-channel signal amplifier was used from a strain gauge with a Wheatstone bridge. This amplifier is compatible with the majority of resistance strain gauges and Arduino Uno/Due microcontroller platforms. It is based on the work of the AD8426 integrated circuit - a two channel, low price measuring amplifier and a wide range of power supply that requires only one external resistor per channel to set any amplification from 1 to 1000. In the applied system, as a standard, the manufacturer mounts 100Ω resistors per channel, which gives a gain of 495, which is almost half of the maximum gain. For the above the gain has a rated output voltage of 980 [mV] for the maximum measuring range of 0.1 [kg]. Assuming a gravitational acceleration equal to 9,8145 [m/s^2] (at Gdańsk city location), a dependence is obtained: for a maximum force of 0.981 [N], a voltage at the output of the amplifier equal to 980 [mV] is obtained.

The value of the output voltage of each channel can be adjusted using two built-in potentiometers. The amplifier also has a second order Bessel second-pass second-pass filter with a frequency limit of 1000 [Hz] for both channels, which gives initial filtration of the measurements obtained.

The 2-channel signal amplifier from the strain gauge with the Wheatstone bridge uses analog inputs A0 and A1 in the Arduino platform standard for the first and second tensometer respectively. Due to the higher computing power of the processor and the built-in ADC converter with higher resolution (12 bits) Arduino Due microprocessor system was used.

Arduino Due is equipped with a microcontroller with ARM 32-bit Cortex M3 core based on Arduino libraries. The Arduino Due board includes the Atmel AT91SAM3X8E chipset, equipped with 54 digital inputs/outputs, of which 12 can be used as PWM outputs and 12 as analog A/C converter inputs. The chipset is clocked at 84[MHz]. It also has interfaces: UART, SPI, TWI (I2C), USB, JTAG and digital-to-analogue converter. Assuming that the result of signal processing from the extensometer is 12-bit and that the reference voltage for the transducer is equal to 3.3 [V], the dependence is obtained that 1 bit corresponds to 0.8 [mN] (about 0.081 [g]). It was assumed that the force measurement path will communicate with the measurement system via a serial link.

3.4.1. Calibration of the measuring path using strain gauges

Calibration process of the strain gauges was carried out as follows:

1. Using a high accuracy scale (up to 1 [g]), 5 ring wrenches were measured, which were used as reference weights for the calibration of strain gauges,
2. Using the written application for Arduino Due, a force measurement was carried out for five reference weights (one end of the strain gauge was mounted in a clamp, and to the other reference weights were – Figure 12.
3. Based on the collected data in the form of masses of weights and corresponding readings from the extensometers, the values of voltages at the output of the measuring amplifier (range 0-4095 bits corresponds to the voltage range 0-3,3 [V]) and force measured by the extensometer (acceleration of 9.8145 [m/s^2] was assumed),
4. On the basis of the measured data, two diagrams were drawn (Figures 13 and 14) allowing to assess the linearity of the functional dependence of the reading/voltage from the force acting on the extensometer, i.e. the gravity of the reference weights).

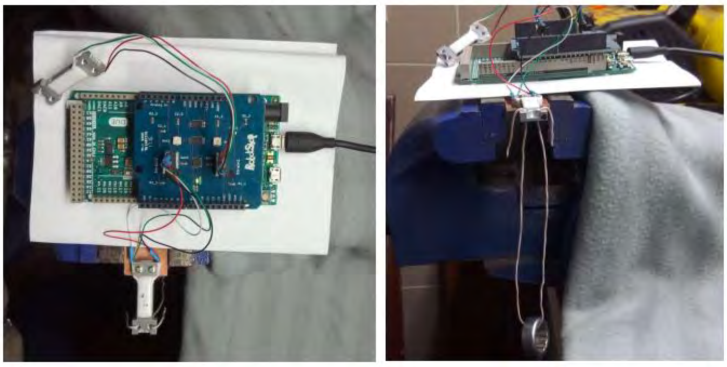
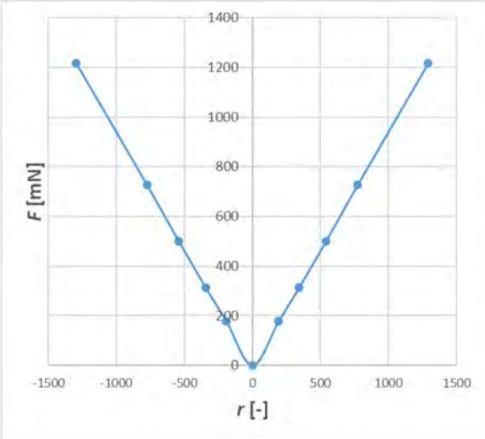


Figure 12 Arduino Due with a 100 [g] tensometer during the calibration: top view (left photo), side view (right photo)

Source: Own study AMW



Graph 1Force *F* in a function of reading *r* from the ADC transducer

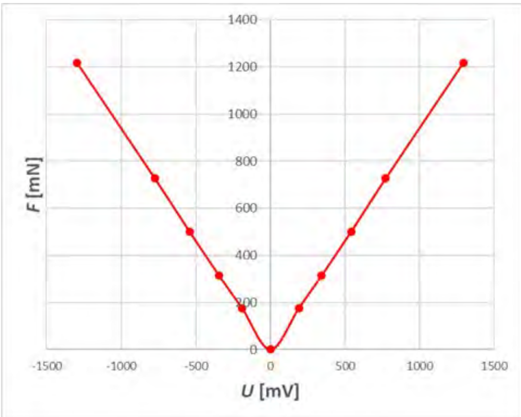
Source: Own study AMW

Based on the collected measurements, a linear function was determined describing the operation of the extensometer in the following form:

$$F = 1{,}151 * U \tag{18}$$

Where:
F – force measured by a strain gauge,
U – voltage at the output of the measuring amplifier.

Taking into account obtained function (18), the force values were calculated based on the registered voltage values. This allowed a further step to determine the relative error and absolute measurement. An absolute error value of 0.91% was obtained and the maximum value of this error was 1.6% - Table 1.



Graph 2 Force graph as a function of the voltage from the output of the amplifier

Source: Own study AMW

Table 1 Accuracy of measurement with a 100 [g] strain gauge (mean relative error 0.91%)

Tension [mV]	Force [mN]	Calculated force [mN]	Absolute error [mN]	Relative error [%]
1042	1217	1199	18	1,45
623	726	717	9	1,28
436	501	502	1	0,25
276	314	318	4	1,30
154	177	177	1	0,28
-154	177	177	1	0,28
-277	314	319	5	1,60
-437	501	503	2	0,44
-625	726	719	7	1,02
-1044	1217	1202	15	1,22

Source: Own study AMW

Calibration of the measuring with the strain gauges allows measurement of the force generated by the undulating propulsion the water tunnel with an average relative error of about 1%. After initial analysis of the possibility of generating force by the designed physical model of the undulating propulsion, it seems that the applied 100 [g] extensometer will cover the full measuring range for the generated thrust with a relatively small error.

3.5. Consument energy measurement

The second very important measurement concerns a consumed energy. This measurement includes measurement of the voltage and current of the oscillating fin and time. This allows you to estimate the amount of energy needed to control the fin at a given amplitude and frequency.

The voltage measurement is carried out via the analog input of the Arduino Due control platform. This platform can use a 10- or 12-bit analog-digital converter. A 10-bit ADC converter was used for voltage measurements. Voltage measurement is carried out by examining the voltage drop across the 6.2 [Ω] resistor. One of the resistor leads is connected to the negative supply voltage and the GND output of the microcontroller. The other terminal of the resistor was connected to the analog input of the microcontroller and by the ammeter to the appropriate input of the servo. The voltmeter measures the voltage drop across the resistor and is connected in parallel to the system. The voltmeter operates on the 2 [V] measuring range, an ammeter on the measuring range of 200 [mA].

Voltage measurement is carried out directly by the microcontroller. The current estimation is done by using Ohm's law in the implemented algorithm.

In order to maintain the fluidity of the measurement, it was decided to measure the rotation of the fin around its own axis in the absence of a forced flow of water. Four measuring tests were carried out for the fin with dimensions 89x90 [mm] for the following rotational speeds of the fins: 0, 8, 16 and 24 [rpm].

3.5.1. Accuracy of the reference measurement

Calculations were made showing the accuracy of the reference devices used. The absolute error of the multimeter for current and voltage measurement has been calculated. The measuring range was unchanged for all tests. The voltage indication on the measuring instrument is denoted as follows: x_v, current indication: x_c

Based on the measurement error, the relative error of the reference devices was estimated, while the results of the calculations made are summarized in Table 2.

In order to estimate the error of the absolute measurement of voltage and current, the value of the least significant digit in the given measuring range was read [catalog card]:

$c_v = 0.001$ [V]
$c_c = 100$ [μA]

Absolute error of voltage measurement ΔX_v and current ΔX_c [catalog note]

$$\Delta X_v = 0.5\% \cdot x_v + 4 \cdot c_v \tag{19}$$

$$\Delta X_c = 1\% \cdot x_c + 5 \cdot c_c \tag{20}$$

Relative error of voltage measurement: δ_v and current δ_c it is calculated from the following formulas:

$$\delta_v = \frac{\Delta X_v}{x_v} \tag{21}$$

$$\delta_c = \frac{\Delta X_c}{x_c} \tag{22}$$

Table 2 Errors of the reference measurement

Measurement	Reading x_v[V], x_c [mA]		Absolute error of the multimeter ΔX_v [V], ΔX_{c1} [mA]		Relative error of the multimeter δ_{v1} [%], δ_{c1} [%]	
1	0.227	36.5	0.0051	0.37	2.26	1.01
2	0.723	119.65	0.0076	1.2	1.05	1
3	0.637	111.95	0.0072	1.12	1.13	1
4	0.590	97.10	0.0070	0.9760	1.18	1

Source: Own study AMW

3.5.2. Accuracy of Arduino measurement

Accuracy of the measurements carried out using Arduino microcontroller started with the determination of the arithmetic mean for each of the measurements. Then the average relative error was estimated, which represents the difference between the reference measurement and the measurement made by the microcontroller as a percentage. The average square error is also presented, which presents the spread of measurements around the average value.

An arithmetic averag:

The arithmetic mean of the voltage measurement $\bar{x}_v$ and current $\bar{x}_c$

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{23}$$

An average relative error:

The average relative voltage error δ_{Av} and current δ_{Ac}

$$\delta_{Av} = \frac{|x_v - \bar{x}_v|}{x_v} \tag{24}$$

$$\delta_{Ac} = \frac{|x_c - \bar{x}_c|}{x_c} \tag{25}$$

An average square error:

An average square voltage error $|\Delta x|_v$ and current $|\Delta x|_c$:

$$|\Delta x| = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}} \tag{26}$$

Table 3 Measurement error

Measurement	Average arithmetical $\bar{x}_v$ [V], $\bar{x}_c$ [mA]		Average error relative δ_{Av} %],δ_{Ac} [%]		Average square error $\lvert\Delta x\rvert_v$ [V], $\lvert\Delta x\rvert_c$ [mA]	
1	0.21	33.75	6.33	7.22	0.0022	0.360
2	0.73	117.69	2.14	5.05	0.0270	4.380
3	0.672	108.45	6.57	5.67	0.0312	5.027
4	0.590	95.23	1.79	5.31	0.0112	1.7986

Source: Own study AMW

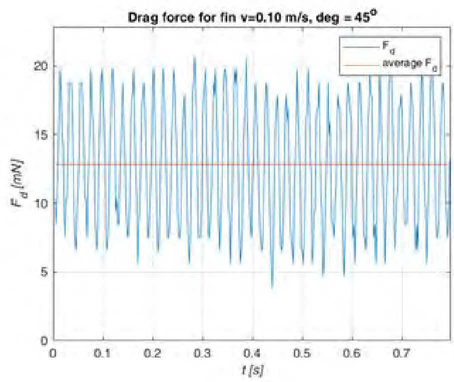
3.6. Water flow and fin deflection measurement using a vision method

The measuring stand is also equipped with a vision system enabling the image processing experiments. Measurements are made using a camera placed over the examined fin that is immersed in water. MATLAB environment allows you to create advanced procedures for computer visualization of measurement and calculation results as well as for effective graphic processing. Therefore, it was selected to work on determining the water flow and deflection of the fin by means of a vision method, using the Computer Vision System Toolbox and Image Processing Toolbox.

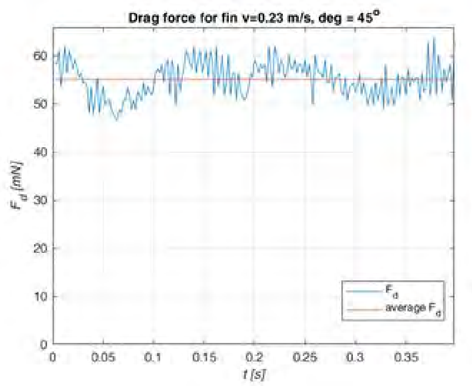
4. INITIAL TEST RESULTS

4.1. Thrust measurement

On the presented measuring stand a resistance force measurement for a fixed fin measuring 89x90 [mm] was carried out. Three deflections of the fin from the neutral position were assumed (the neutral position was determined as the position of the fin in the direction of the fluid flow): 45, 60, 75 degrees. The flow velocity was controlled using a pump forcing water flow. Two types of characteristics are presented below. The first shows the resistance force for selected swing angles and selected flow velocities. Additionally, the average value of the resistance force measurement for a given fin position and the given flow velocity was placed on the characteristics. The second type of characteristic presents the average values of the resistance force for the mentioned fin positions at full regulation of the fluid flow velocity.



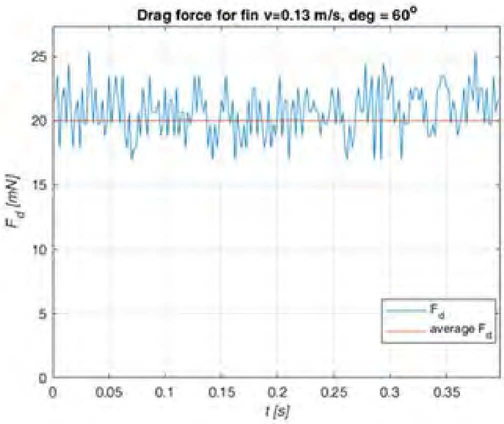
a)



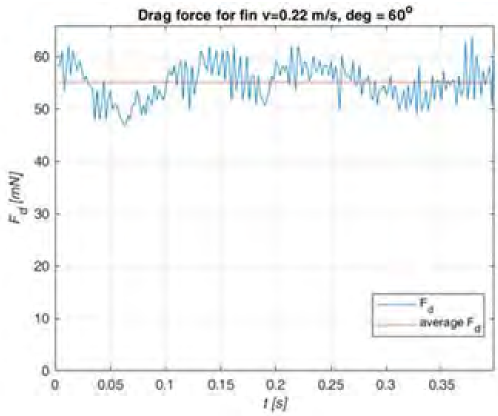
b)

Graph 3 Drag force for F_d for fin with 45 [deg] deflection in the presence of flowing water with velocity: a) v = 0.1 [m/s], b) v= 0.23 [m/s]

Source: Own study AMW



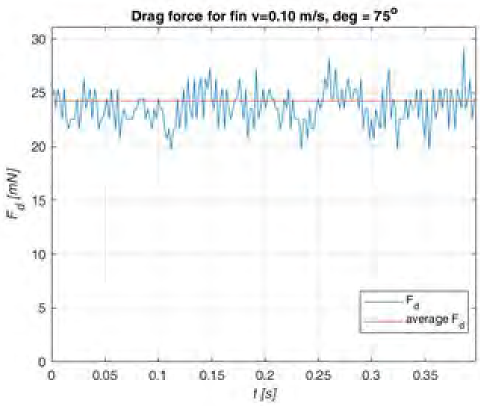
a)



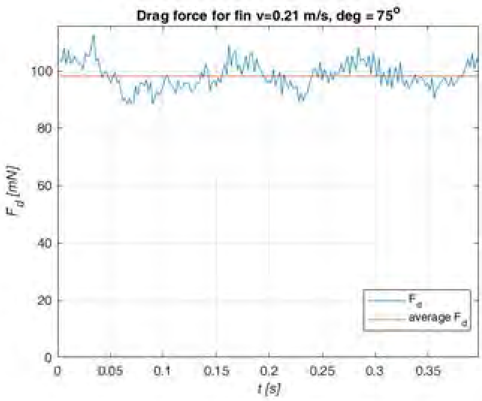
b)

Graph 4 Drag force for F_d for fin with 60 [deg] deflection in the presence of flowing water with velocity: a) v = 0.13 [m/s], b) v= 0.22 [m/s]

Source: Own study AMW



a)

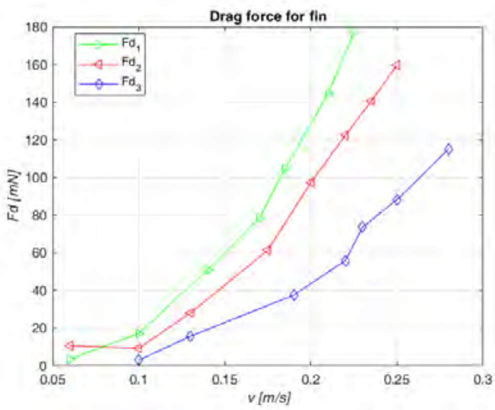


b)

Graph 5 Drag force for F_d for fin with 75 [deg] deflection in the presence of flowing water with velocity: a) v = 0.1 [m/s], b) v= 0.21 [m/s]

Source: Own study AMW

The characteristic marked F_{d1} shows the nature of the change in resistance to deflection 75 [deg] for increasing fluid velocity. The F_{d2} characteristic shows the resistance force depending on the fluid velocity for the deflection of the fin equal to 60 [deg]. The last characteristic labeled F_{d3} shows the resistance force for 45 [deg] deflection.



Graph 6 Average drag force for the fin in the presence of flowing water with changing velocty

Source: Own study AMW

The value of the resistance force can be calculated according to the following formula:

$$F_d = \frac{1}{2}\rho v^2 C_d A \tag{27}$$

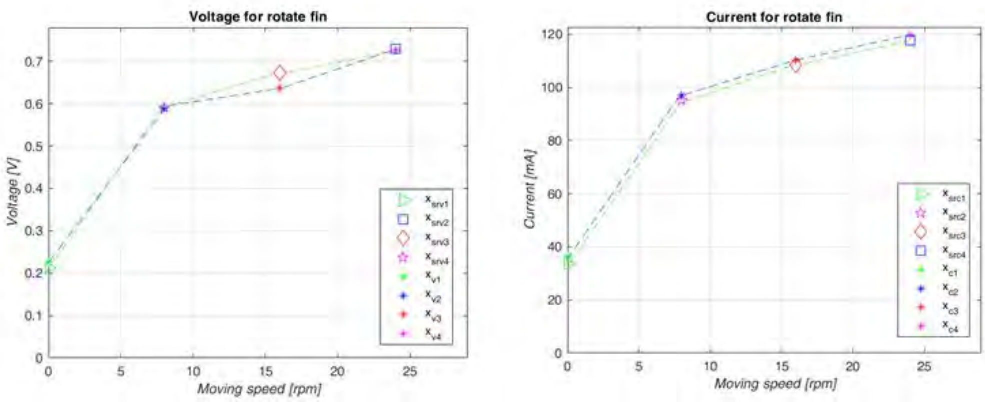
Where: ρ – fluid density, v – fluid velocity, C_d – coefficient of resistance, A – cross-section

With the increase of the fluid flow speed, the resistance force for the fixed fin increases. The value of the resistance force depends also on the cross-sectional area. As the surface increases (along with the increase of the fin's deflection), the resistance force for the same value of the fluid velocity increases.

4.2. Voltage and current measurement

The following characteristics show the average results of voltage and current measurements made using a microcontroller for different rotational speeds of the fin.

The characteristic with points from x_{srv1} to x_{srv4} is the voltage measurement made by the microcontroller. The second characteristic with measuring points marked from x_{v1} to x_{v4} shows the measurement of the reference voltage made with an additional voltmeter. The characteristics representing the current consumption were similarly analogous: characteristics with points. Measurement done with a microcontroller is marked as x_{src1} to x_{src4}. The reference measurement was presented from x_{c1} to x_{c4}.



Graph 7 Measurement of current and voltage carried out by Arduino for different rotating speeds of the fin

Source: Own study AMW

Characteristics which present current and voltage was realized for different speed of rotate fin. Increase of fluid flow, causes increase of voltage and current. Precision of measurement was researched. Maximum of average error relative equal near 7 percentage. This error present the highest value for velocity equal 0. For this case, servomotors used energy to hold its position.

5. CONCLUSION

The presented water tunnel for the undulating propulsion system analysis was designed with careful consideration of all aspects connected with fluid - structure interaction. The water tunnel dimensions were chosen for laminar flow of the fluid. The fluid flow can be controlled in a wide range of velocity. Actuator used to move the fin can be adopted for different angular speed, frequency motion and power consumption. Some prototypes of the fin were made in incremental plastics technology what gives wide variety of different shapes and construction parameters. For the undulating propulsion optimization purposes the output force to the input energy ration has to be considered. That is why the power input measurement system was calibrated. The accuracy of the designed water tunnel subsystems were elaborated with focus on the accuracy of the measurements.

Preliminary measurements proved that the designed and constructed laboratory test stand meets the design assumptions and requirements. It is possible to measure the output to input energy ratio, so the different characteristic as a function of construction and control signals can be achieved and propulsion system optimization can be performed.

To carry out the numerical simulations LS-DYNA Incompressible Computational Fluid Dynamics (ICFD) solver can be used. The modern and efficient solver may run as a stand-alone CFD solver, where only fluid dynamics effects are studied, or it can be coupled to the solid mechanics solver to study loosely or strongly coupled Fluid-Structure Interaction (FSI) problems. The designed laboratory stand is prepared for verification of the simulation model in lower scale. After a positive verification of the simulation model in the designed laboratory stand the real dimensions model is to be used for investigation of the propulsion system parameters.

The research results from the fin in the designed water tunnel will be used for the selection of the electric motor and the calculation of the battery size for the assumed speed and range of the BUV. In addition, the selection of appropriate parameters of the elastic tail fin (such as a shape, a stiffness, an amplitude and a frequency of oscillations) gives the opportunity to approximate the reproduction of complex fish movements, taking into account the improvement of speed and the efficiency of the propulsion.

ACKNOWLEDGMENT

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REFERENCES

[1] Bessa M. W., Dutra M. S., Kreuzer E. Depth control of remotely operated underwater vehicles, Robotics and Autonomous Systems, 2008, Vol. 56, No 8.

[2] Colgate J. E., Lynch K. M., Mechanics and Control of Swimming: A Review, IEEE Journal of Oceanic Engineering, 2004, Vol. 29, No 3, pp 660-673, DOI: 10.1109/JOE.2004.833208.

[3] Dongwon Y., Jinho K., Chanhun P.Experiment of Thrust Characteristic of a Robot Fish Swimming, 11th International Conference on Control, Automation and Systems, South Korea, 2011, Vol. 11.

[4] Flammang B. E., etc., A robotic fish caudal fin: Effects of stiffness and motor program on locomotor performance, Journal of Experimental Biology, 2012, Vol. 215, No 1, pp 56-67, DOI: 10.1242/jeb.062711.

[5] Flammang B. E., etc. Building a Fish: The Biology and Engineering Behind a Bioinspired Autonomous Underwater Vehicle, Marine Technology Society Journal, 2017, Vol. 51, No 5, pp 15-22, DOI: https://doi.org/10.4031/MTSJ.51.5.1.

[6] Fossen T., Handbook of Marine Craft Hydrodynamics and Motion Control, Wiley, 2011, DOI:10.1002/9781119994138.

[7] Jezowiecka-Kabsch K., Szewczyk H., Mechanika płynów: Wroclaw University of Technology, 2001. [Fluid mechanics – available in the Polish language].

[8] Jurczyk K., New proposal concerned with displaying underwater vehicle parameters, Scientific Journal of Polish Naval Academy, Poland, 2017, Vol. 209, No 2, pp 61-74, DOI: https://doi.org/10.5604/01.3001.0010.4067.

[9] Koca G. O., Bal C., Three-Dimensional Modeling of a Robotic Fish Based on Real Carp Locomotion, Applied Science, 2018, Vol 180, No 8, DOI: 10.3390/app8020180.

[10] Kubrak E., Kubrak J., Podstawy obliczeń w mechanice płynów w inżynierii i ochronie środowiska, Warsaw, SGWW, 2010. [Basics of calculations in fluid mechanics in engineering and environmental protection– available in the Polish language].

[11] Liu J., Hu H., Gu D. A Hybrid Control Architecture for Autonomous Robotic Fish, In: Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, China, 2006, pp 312-317.

[12] Low K.H., Modelling and parametric study of modular undulating fin rays for fish robots, Mechanism and Machine Theory, 2009, Vol. 44, pp 615-632, DOI 10.1016/j.mechmachtheory.2008.11.009.

[13] Malec M., Wpływ Parametrów Konstrukcyjnych na trajektorię ruchu podwodnego robota mobilnego z napędem falowym, Cracow University of Technology, Faculty of Mechanical Engineering, Kraków, 2018. [Influence of Construction Parameters on the trajectory of Unmanned Underwater Vehicle with undulating propulsion. PhD thesis – available in the Polish language].

[14] Mustafa A., Deniz K. , Gonca O., Mechatronic Design and Manufacturing of the Intelligent Robotic Fish for Bio-Inspired Swimming Modes,Electronics, 2018, Vol 118,No 7, DOI: https://doi.org/10.3390/electronics7070118.

[15] Park Y., Useok J., Kwon S. Kinematic Condition for Maximizing the Thrust of a Robotic Fish Using a Compliant Caudal Fin, IEEE Transactions on robotics, 2012, Vol. 28, pp 1216-1227, DOI: 10.1109/ TRO.2012.2205490.

[16] Szymak P., Simulation and control of biomimetic underwater vehicle with undulating propulsion. WSEAS TRANSACTIONS on SYSTEMS, 2016, Vol 15, pp 180-187, e-ISSN: 2224-2678.

[17] Szymak P., Bruski S. Microprocessor system for measurement of a thrust generated by an underwater vehicle, Applied Mechanics and Materials, 2016, Vol. 817, pp 162-167, DOI: https://doi.org/10.4028/www.scientific.net/AMM.817.162.

[18] Szymak P., Przybylski M., Thrust measurement of biomimetic underwater vehicle with undulating propulsion, Scientific Journal of Polish Naval Academy, Poland, 2018, Vol. 213, No 2, pp 69-82, DOI:10.2478/sjpna-2018-0014.

[19] Taler D., A new heat transfer correlation for transition and turbulent fluid flow in tubes, International Journal of Thermal Sciences, 2016, Vol 108, pp.108-122, DOI: 10.1016/j.ijthermalsci.2016.04.022.

[20] Tesch K., Mechanika Płynów, Gdansk, Gdańsk University of Technology, 2008. [Fluid mechanics – available in the Polish language].

[21] Tokic G., D. K. P. Yue, Optimal Shape and Motion of Undulatory Swimming Organisms, Proceedings of the Royal Society B: Biological Sciences 279, 2012, no. 1740, pp 3065-3074, DOI: https://doi.org/10.1098/rspb.2012.0057

[22] Wang J., Alequin-Ramos F., Tan X.Dynamic modeling of robotic fish and its experimental validation, In: Proceedings of the 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems, San Francisco, 2011.

[23] PN-76/M-34034. Rules for calculating pressure losses. Warsaw : PKNiM, 1978

SUSTAINABLE DEVELOPMENT OF SUBMARINE OPTICAL CABLE INFRASTRUCTURE: TECHNICAL AND LEGAL ASPECTS

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Summary

Submarine optical cables are one of the main components of national and international telecommunication networks. Today, a growing demand for the transfer of large amounts of data at high speeds increases the development and expansion of terrestrial and submarine communication networks. The daily dependence of our society on the Internet creates the demand for fast internet access availability to all users, including those living on the outermost islands of the Adriatic. This underwater cable infrastructure, as a transmission medium is gaining vital importance for the global society and becoming one of the most important strategic goals in the development of the Republic of Croatia. Therefore, coordinated efforts are required between the cable industry, telecommunications operators and governments to ensure maximum availability, protection and reliability of the submarine cable network. By analysing positive legal regulations which are directly or indirectly associated with the issue of laying and maintaining submarine optical cable infrastructure, the integrity and efficiency of the legal framework pertaining to the construction and protection of the submarine cable infrastructure implemented in the Republic of Croatia will be evaluated and potential legal solutions offered. Based on multidisciplinary research which has identified deficiencies related to the construction and utilization of submarine optical cable infrastructure, this paper aims to provide guidelines for the sustainable development of submarine optical cable infrastructure from the technical and legal aspect.

Keywords: submarine optical networks, marine environment, legislation

1. INTRODUCTION

Submarine optical cable infrastructure, i.e. energy and telecommunication cables are important submarine objects from both the economic and legal standpoint. Thus, their reliability, high-quality mechanical and transmission characteristics contribute to a better and more efficient connection and integration of coastal and island population within the global power supply and communication network. This paper will deal exclusively with submarine optical communication networks.

Submarine optical cables are one of the most important segments of national and international telecommunication networks. Nowadays, the demand for broadband services is constantly increasing.

Transmissions of large amounts of data at high speed stimulate the continuous development and expansion of terrestrial and submarine telecommunication networks.

Submarine optical cable networks play an important role in the international telecommunication networks with 98% of all intercontinental communications being transmitted by submarine optical cables. Due to their small size, submarine optical cables generally have a negligible impact on the marine environment. However, activities associated with their design, installation, repairs and maintenance may cause damage and sometimes even long-term changes in ecologically and biologically highly sensitive marine environments. This paper analyses such activities and their impact on the marine environment and also deals with the potential damage of the submarine cables and threats they are exposed to due to human activities and natural factors. The paper also provides guidelines on how to improve their installation and protection in technical and legal terms.

2. SUBMARINE OPTICAL NETWORKS

The first submarine optical cable was installed in the Loch Fyne fjord in Scotland. Since then, several million kilometres of submarine cables have been laid in the oceans and seas around the world. Since the installation of the first transatlantic optical cable in 1988, the optical cable systems have become increasingly important in information transmission. Reliable transmission of information, primarily generated by web applications, has become of vital importance for the global economy.

At present, there are over 400 optical cable systems that are either active or in the process of installation. Antarctica is the only continent on Earth that is currently not connected with the submarine optical cable network. One of the longest submarine optical cable systems in the world is the Southeast Asia-Middle East-Western Europe 3 system (SE-ME-WE-3), with the total installed length (including branches) of almost 40,000 km. [12]

Optical cable systems are used to transmit information at speed that is equal to 99.7% of the speed of light, which is a significant advantage in comparison to satellite communication systems. Apart from that, other advantages of using optical cable systems as opposed to satellite systems is the higher level of safety and reliability and more efficient methods of installation and repairs. However, submarine cables are more susceptible to damage and failures caused by various human and natural factors. In order to improve methods of installation, maintenance and repair of submarine cables, first it is necessary to analyse and understand the causes of failures and potential threats that can endanger safety and reliability of the network operation. All the measures and procedures should be applied in accordance with the sustainable exploitation/use of submarine and coastal areas. [2], [8], [10], [17]

Submarine optical cables have been installed in the Croatian telecommunications network since the beginning of the 90s, almost simultaneously with the construction of the core terrestrial network. Since they are constituent parts of the core network, submarine optical cables are used to connect transmission devices, land and mobile telecommunication networks on islands with communication centres nodes situated on land. Submarine optical cables laid to Italy and Greece additionally increase the capacity and quality of Croatia's international connections with the rest of the world. So far, in the part of the Adriatic belonging to Croatia's territorial waters, around 800 km of submarine optical fibre cables have been laid, connecting approximately 30 islands. Maximum depth at which the cables have been laid is 100 m. Since the distances between the islands are relatively short, there was no need to install optical amplifiers on the seabed.

3. LEGAL ASPECTS OF SUBMARINE OPTICAL CABLE INFRASTRUCTURE DESIGN AND APPLICATION

Since the infrastructure of the submarine optical fibre network is quite sensitive by its nature, the need has arisen to legally regulate its use and thus improve its protection. There are laws dating back to 1880s that refer to laying of cables. The most important legal text referring to high seas is the United Nations Convention on the Law of the Sea - UNCLOS. The Convention defines the rights and responsibilities of nations with respect to their use of the world's oceans, establishing relevant guidelines concerning business, environment and the management of marine natural resources. UNCLOS entered into force in 1994 and as of June 2016, 168 countries, including the European Union, ratified the Convention. UNCLOS affords the freedom to lay submarine cables and maintain and repair them outside territorial waters. [16]

Chief regulatory instrument for the protection of the Mediterranean marine and coastal environment is the Barcelona Convention for the Protection of the Mediterranean Sea against Pollution, which entered into force in 2004. Today, all 21 countries that have access to the Mediterranean Sea, including the EU countries, are included in the Barcelona Convention. Barcelona Convention primarily deals with the issues associated with the physical damage of the seabed that is the result of the human influence (including construction at sea, dredging and fishing). However, the Convention does not offer special regulations that refer to the use of submarine cables. Adoption of standards and regulations associated with the territorial waters is left at the discretion of each costal state. [15]

3.1. International legal framework pertaining to the right of installing and legally protecting submarine cables

Legal regulations governing cable laying and cable maintenance and application of associated legal solutions depends on the marine and submarine areas in question. If the inland waterways and territorial waters are in question, they are integral parts of coastal state's territory and as such they are subject to its sovereignty and jurisdiction. Submarine cables and pipelines that are laid in inland waterways and territorial sea are subject to jurisdiction and sovereignty of the coastal state. The sovereignty of a costal state is realized according to the Convention of the territorial sea and contiguous zone of 1958 and the UN Convention on the Law of the Sea of 1982 and other international regulations. In terms of legal protection, submarine cables laid in these sea areas are subject to coastal state's rules and regulations.

Another area in which submarine cables and pipelines can be laid is the continental shelf Continental shelf is the area outside coastal state's jurisdiction, over which coastal state has no sovereignty apart from specific sovereign rights for the purpose of research and exploitation of natural resources and those rights are exclusive. The right to lay submarine cables is regulated by article 79, paragraph 1 of the UN Convention on the Law of the Sea of 1982 ("All States are entitled to lay submarine cables and pipelines on the continental shelf, in accordance with the provisions of this article"). In exercising this right, the states are required to adhere to the specific terms and conditions set forth by the Convention. Above all, when laying submarine cables or pipelines, States shall have due regard to cables or pipelines already in position. In particular, possibilities of repairing existing cables or pipelines shall not be prejudiced unless the coastal state is taking reasonable measures for the exploration of the continental shelf, the exploitation of its natural resources and the prevention, reduction and control of pollution from pipelines.

In order to protect the interests of the coastal State to a certain extent, the Convention on the Law of the Sea grants the right to a coastal State to establish conditions which other states will have to adhere to while delineating the course for the laying of such cables and pipelines on its continental shelf. If submarine cables and pipelines laid on the continental shelf enter the territorial waters or territorial sea of the coastal State, then laying of such cables and pipelines will be subject to prior approval by the coastal State.

The right to lay submarine cables and pipelines on the bed of the high seas beyond continental shelf is regulated by Article 112, paragraph 1 of the Convention on the Law of the Sea („All States are entitled to lay submarine cables and pipelines on the bed of the high seas beyond the continental shelf."). As with the laying of cables and pipelines on the continental shelf, the coastal States shall have due regard to cables or pipelines already in position. In particular, possibilities of repairing existing cables or pipelines shall not be prejudiced.

If breaking or injury of a submarine cable or pipeline laid on the bed of the high seas occurs, according to the provisions of Article 113 of the Convention on the Law of the Sea, such occurrence shall be considered a punishable offence. In case of breaking or injury of submarine cables or pipelines, the jurisdiction for such offence will depend on whether the act was carried out by a ship or by a person. If breaking or injury was caused by a ship, it will be subject to the jurisdiction of the flag state. Likewise, if breaking or injury is caused by a person, it will be under the jurisdiction of the State that person is subject to. Legal protection of submarine cables and pipelines laid on the bed of the high seas is regulated entirely by article 113 of the Convention on the Law of the Sea.

Article 114 of the Convention on the Law of the Sea stipulates the obligation of each State to adopt laws and regulations pertaining to making up the cost incurred as a result of breaking or injury of a submarine cable or pipeline of another owner caused by the owner of cable or pipeline subject to the State's jurisdiction.

Also, every State shall adopt the laws and regulations necessary to ensure that the owners of ships who can prove that they have sacrificed an anchor, a net or any other fishing gear, in order to avoid injuring a submarine cable or pipeline, shall be indemnified by the owner of the cable or pipeline, provided that the owner of the ship has taken all reasonable precautionary measures beforehand (Article 115 of the Convention on the Law of the Sea).

3.2. National legal framework pertaining to the right of installing and legally protecting submarine cables

The laying and maintenance of submarine cables in the Republic of Croatia is regulated by a number of legal acts and subordinate legislation.

The Maritime Code of the Republic of Croatia contains several provisions regarding submarine cables. However, it must be stressed that the Croatian Maritime Code does not provide a definition of submarine cables and in certain Articles of the Maritime code they are classified as floating objects. The first provision pertaining to the laying of submarine cables is included in Article 45, paragraph 3 of the Maritime Code, stipulating the jurisdiction of the associated Ministry during the laying of cables. The Ministry issues an approval for those submarine cables that are to be laid on the continental shelf of the Republic of Croatia and extend into its territorial sea. The Ministry also has the authority to monitor the laying and maintenance of these submarine cables. By adopting this provision, the Republic of Croatia has exercised its legal right as stipulated by the Convention on the Law of the Sea (Article 79, paragraph 4). [13]

It is important to emphasize that the laying and maintenance of submarine cables without the approval of the Ministry constitutes a maritime offence according to Article 993 of the Maritime Code.

In order to protect the submarine cables from potential damage, the Maritime Code prescribes the procedures associated with the installation and maintenance of the special sea marks which mark objects, facilities or operations at sea or ashore that are considered permanent or temporary obstacles in the fairway. These objects also include submarine cables. In accordance with Article 52, paragraph 4 of the Maritime Code, the person responsible for the installation and maintenance of special marks is the investor, owner or user of the object or facility.

Submarine cables are also exposed to threats and damage from vessels. Article 811 of the Maritime Code does not explicitly stipulate the liability of the vessel for injuries caused to submarine cables, but it does stipulate the liability of the vessel for damage caused to wharves, breakwaters, port facilities, equipment and floating objects, which also include submarine cables. The liability of the vessels implies the liability of the ship owner or operator.

The protection of submarine cables is prescribed by Article 840.I of the Maritime Code, which associates submerged wrecks that pose danger to safety of navigation with other objects such as submarine cables. In fact, submarine cables are one of the factors or elements taken into consideration in determining whether a submerged wreck poses any danger.

Apart from the Maritime code, another significant legal document pertaining to submarine cables is the Regulation on conditions for the authorization for laying and maintenance of submarine cables and pipelines on the continental shelf of the Republic of Croatia. The Regulation also prescribes the conditions for monitoring their installation and maintenance. Unlike the Maritime Code, the above mentioned Regulation provides a definition of submarine cables. Thus, in accordance with Article 2 of the Regulation, submarine cables are telecommunications or power supply cables laid beneath the sea surface, either on the sea bed or buried into it.

In order for the submarine cable to be laid or buried into the seabed, it is necessary to procure the following permits and approvals: location permit, building permit, operating permit and cable corridor approval. Apart from the above mentioned documents, since these activities entail a special use of the maritime demesne, the investor must apply for a concession and enter into a concession agreement. The procurement of the aforementioned documents and various other requirements that are to be met are prescribed in a number of different provisions and under jurisdiction of different ministries and authorized bodies, which renders the laying of submarine cables a rather complex and demanding procedure. [7], [9], [14]

4. IMPACT OF THE SUBMARINE CABLE NETWORK INSTALLATION ON THE MARINE ENVIRONMENT

Submarine optical fibre cables are intended to be used in highly demanding marine environments. Optical fibres in the cable core are covered with additional claddings and strength elements that protect them from water, pressure, waves, currents and other natural forces acting at sea. Some of these factors vary with depth of water. Thus, for instance, the effects of temperature and waves decrease with depth, while the pressure increases. On the other hand, sea currents can cause the shifting and damage of cables at any depth.

The laying of cables is preceded by a number of activities of both technical and legal nature. Based on the telecommunications network operators or owners' business decisions, landing points are determined, where the submarine cables are then connected to the terrestrial cable network. Also, as stated previously in the paper, various permits and approvals for the use of the seabed and the coastal area must be obtained.

At larger depths, the submarine cables are usually laid directly on the seabed without any protection. However, on shallow sandy bottoms, the submarine cables are buried in cable trenches. (Fig. 1)

Compared to submarine pipelines, submarine optical cables are very small. Their diameter varies from 17 mm to 50 mm and their impact on the seabed ecosystem is negligible. However, a number of activities associated with the laying of cables, their connection to terrestrial networks, maintenance and repair can cause permanent harmful damage to the seabed and have detrimental effects on the submarine living organisms.

Proper installation, maintenance and repair of submarine optical cables can guarantee their minimal impact on the marine environment. It has been noticed that the seabed the cable has been laid on recovers after a certain amount of time. Naturally, the materials used for cable coating must be non-toxic and stable in salt water. Emission of harmful substances from the cable is negligible because the potential pollution can only be caused by the conductors and cable's galvanized steel armour. These metal parts of the cable are made of copper, iron and zinc, out of which only zinc can enter in sea water in negligible concentrations. Polyethylene coating of the cable is inert in sea water.

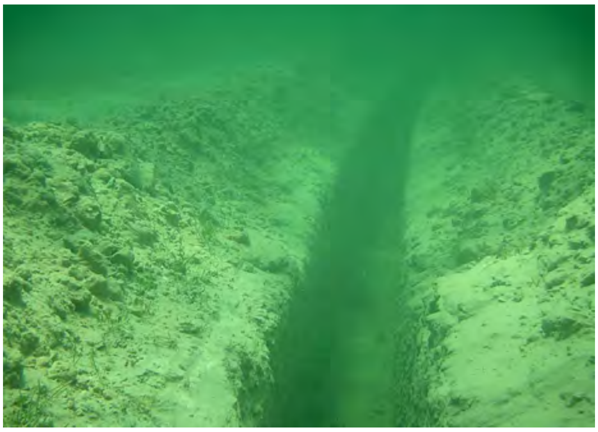

Figure 1 Cable trench on shallow sandy sea bottom

Source: Author

4.1. Cable route selection

Cable route selection is primarily determined by the telecommunication network operator's business plans as well as by the findings of submarine surveys and legal requirements for obtaining all the necessary cable-laying permits. Apart from that, it is also important to choose the suitable landing points, where the submarine cables are to be connected to terrestrial optical networks. Surveys of the seabed are usually carried out by survey vessels equipped with multi-beam sonar systems and satellite navigation systems. Surveys of the seabed help in identifying rocky bottoms, wrecks and other submarine installations that are to be avoided during cable-laying. During installation, repairs and maintenance of submarine cables, there are different elements affecting the marine environment that require the environmental impact assessment.

Environmental impact assessment report should determine the present condition of the submarine cable infrastructure; analyse failures, repair procedures, cable-laying and cable-protection methods; prescribe terms and conditions for the installation, repair and maintenance of submarine cables; define the types of cable-laying vessels and their equipment; determine the corridors in which fishing and anchoring is prohibited; establish protected marine areas; prescribe the requirements for cables entering the territorial waters; ensure maximum protection of both cable infrastructure and marine environment.

4.2. Cable installation

Regular transmission of information via submarine cable network depends on the quality of installed components and cables and the adequate cable-laying methods. The basic concepts of design crucial for the safe and economical cable installation are the following: suitable route selection, suitable knowledge of cable characteristics, experience in laying and protection of submarine cables in different environmental conditions.

Construction of landing points and laying and protection of cables must not damage the coastal and submarine environment in which these activities are taking place. Suitable and ecologically sustainable selection of landing points and construction of cable protection contributes to preservation of the natural environment. Also, the cables themselves have to be protected in order to ensure a reliable and high-quality transmission of information and eliminate failure and damage. (Fig. 2)

In areas where there is a possibility of damage to the cables due to human activity, the cables are usually buried in the seabed or protected by concrete moulds. It is customary to protect cables up to -10 meters of sea depth. At larger depths, the cables are laid on the seabed without additional protection. Damage to the seabed are caused by using a combination of ploughing and jetting for burial. Since cable lifetime is approximately 20 to 25 years, seabed recovers once the cable has been buried. The laying of cables affects the seabed in the width of approximately 5 to 8 meters. In comparison, trawling causes damage to seabed in width of more than 10 metres.

In order for the optical network to be resistant to failure and to provide continuous high-quality service, it is necessary to carry out regular maintenance and monitoring of the network. (Fig. 3) Once the cables' lifetime has expired or when it is necessary to replace them because they have become technically outdated, they must be removed from the seabed. Unfortunately, these cable removal operations also cause damage to marine environment. [4-6]

Figure 2 Optical cable coastal protection with a layer of sand-cement bags

Source: Author

Figure 3 Optical cable maintenance on the seabed

Source: Author

5. PROTECTION OF SUBMARINE OPTICAL CABLE NETWORK

When it comes to protection of submarine cables, conservation of the marine environment must be of paramount importance. Cable repairs are generally long-term activities that require the use of cable-laying vessels. Furthermore, when international cable systems are in question, it is necessary to obtain cable work permits from a number of states, which additionally extends the duration of repairs.

Although there does not exist a central data base with all the information on cable failures, some estimates have shown that approximately 100 to 150 failures occur annually worldwide. Most of them occur in coastal waters at the depths of up to 100 meters. [1], [11]

The most common threats to submarine cable networks are posed by human negligence and natural factors. The most frequent failures caused by human factor are fishing, anchoring and piracy. Natural disasters are rare, but when they do occur, they can cause extensive damage to submarine networks found in the affected area. Disruptions due to natural causes amount to less than 10% of the total number of failures.

5.1. Fishing

Trawling in coastal areas causes 44,4% of submarine cable disruptions. Annually, 50-100 cable failures caused by trawling result in communication network disruption and incur substantial repair costs. Furthermore, trawling on muddy seabed affects the seabed up to the depth of 5-20 cm. If the cable is buried at the depth of approximately 60 cm into the seabed, there is less likelihood of contact and damage. However, cable laid on the seabed can be damaged by fishing gear. If the cable is laid without suitable protection, fishing gear can sometimes cut through the optical cable cladding.

One of the methods of protecting the cables from fishing activity is surveying the seabed in order to determine the safest cable routes. In coordination with national bodies, it is necessary to establish safe zones for submarine cables, where anchoring and fishing would be prohibited. Such zones could also provide protected areas for endangered marine species. Naturally, if it is possible, the best protection of cables is achieved by burying them in the seabed. Fishermen could attend special educational programmes on the importance and methods of preventing cable damage. They could also be provided with all-day telephone support service in cases of cable damage and regularly updated sea charts showing new cable installations. In areas with intense fishing activity, cable routes should remain free in order to ensure safe manoeuvring of cable-laying vessels.

5.2. Anchoring

Anchoring is the second biggest cause of cable disruption and amounts to 14,6% of all cable failures. If several cables are installed close to one another at short distances, it is possible to damage all of them simultaneously. Even if such disruptions immediately raise the alarm on the transmission devices, showing the exact location of failure, it is still difficult to locate the torn ends of the cable because they can fall on the sea bottom or be dragged away by the anchor hundreds of miles from their initial position. The search for the torn ends of the cable is performed by divers or remote operated vehicles (ROV) at larger depths.

In order to protect the cables against ships' anchors, it is best to bury them into the seabed near ports, where port authorities should establish safe zones for submarine cables away from the anchoring areas and port approaches. The use of AIS (Automatic Identification System) could also contribute to the protection of submarine cables since it could provide timely information on the potential risks of damage to submarine cables due to vessels dragging.

Figure 4 Optical cable breakage caused by anchoring

Source: Author

5.3. Piracy

Any intentional disruption and damage to submarine cables is considered an act of piracy. Cases of cable wire theft have been recorded, especially during cable installation process. Since the process of installation lasts for several days, reels of cables are left on the buoys or rafts during the night or during breaks. As a result, in certain cases, hundreds of meters of submarine cables have been stolen.

Protection from piracy and prevention of pirate attacks is the responsibility of governments and is considered a legislative issue. In cases of piracy, protocols between different state agencies should be clearly defined in order for the appropriate actions to be taken quickly. Such legislation should be applied both to national and international submarine cables, ensuring their protection from pirate and terrorist attacks. Protocols that should be followed in cases of piracy should include telephone contacts for emergency situations by which owners of cable infrastructure could be immediately notified for repairs. This requires accurate and updated information on the owners of cable infrastructure, as well as on the types and routes of submarine cables. Regular piracy attack drills should also be carried out in order to improve the response of all the participants in the protocol. Such drills could also help identify new ways to reduce the impact of this type of security threat.

6. CONCLUSION

By improving the process of submarine cable laying, maintenance and repair and by establishing efficient methods of optical cable network protection, a great contribution could be made to the preservation of the marine environment. Reducing the risk of damage in selecting the suitable cable routes and landing points, establishing safe cable laying zones and enforcing the laws pertaining to the exploitation of the submarine environment would result in more resilient submarine cable networks both in national and international waters. Since the application of legislation is of great importance for the protection of submarine cable networks, national coastal law must be in conformity with the relevant international laws and conventions.

It is also necessary to define the rules and regulations referring to all the activities associated with laying, maintenance and repair of submarine optical cables and to the type of mandatory equipment to be used by specialized vessels for cable repair.

Using up-to-date vessel monitoring technology and providing timely feedback on cable installation work would significantly reduce the risk of failure caused by human activity. At the same time, faster transmission of information regarding cable failures would reduce the time necessary to locate them and thus reduce their repair time.

All of the above mentioned activities require coordinated efforts by a number of participants. These participants are telecommunication operators, cable infrastructure owners, cable manufacturers, shipping companies, hydrographic institutes, port authorities and government agencies responsible for the management of marine and coastal areas. It is only the coordinated efforts of all of the above mentioned participants that can promote the awareness and knowledge of the ecologically sustainable laying of optical cables in the submarine environment and thus ensure they become global green communication networks.

REFERENCES

[1] Carter L., et al.: Submarine cables and the oceans: connecting the world, The International Cable Protection Committee, 2009, https://www.iscpc.org/, accessed July 8, 2019.

[2] Chesnoy, J.: Undersea Fiber Communication Systems, Academic Press, 2002

[3] Drew, S. C., Hopper, A. G.: Fishing and Submarine Cables-Working Together, Second edition, The International Cable Protection Committee, February 23, 2009

[4] Jurdana, I., Ivče, R., Glažar, D.: Submarine Optical Cables: Impact on the Marine Environment, 56th International Symposium "Electronics in Marine" ELMAR 2014., Zadar, Croatia, 2014

[5] Jurdana, I., Ivče, R.: Coastal Protection of Submarine Optical Cables: Croatian Experiences, 55th International Symposium "Electronics in Marine" ELMAR 2013., Zadar, Croatia, 2013

[6] Jurdana, I., Sučić, V.: Submarine Optical Networks: How to Make Them Greener, The 16th International Conference on Transparent Optical Networks ICTON 2014, Graz, Austria, 2014

[7] Ordinance on conditions for the issuing of approval for laying and maintenance of submarine cables and pipelines on the continental shelf of the Republic of Croatia Official Gazette of the Republic of Croatia - Narodne novine, No. 126/07.

[8] Ramaswami, R., Sivarajan, K. N., Saski, G. H.: Optical Networks: A Practical Perspective, 3rd ed., Elsevier, 2010

[9] Rukavina, B., Legal protection of deep-sea cables and pipelines within international conventions and national legislation, Pomorski zbornik 38 (2000) 1, p. 191-199.

[10] Selvarajan, A., Kar, S., Srinivas T.: Optical Fiber Communications: Principles and Systems, McGraw-Hill, 2006

[11] Submarine Cables and BBNJ, The International Cable Protection Committee, August 1, 2016, https://www.iscpc.org/, accessed July 8, 2019.

[12] TeleGeography's Interactive Submarine Cable Map, updated June 28, 2019, https://www.submarinecablemap.com, accessed July 8, 2019.

[13] The Maritime Code, Official Gazette of the Republic of Croatia - Narodne novine, No. 181/04, 76/07, 146/08, 61/11, 56/13, 26/15, 17/19.

[14] The Maritime Domain and Seaports Act Official Gazette of the Republic of Croatia - Narodne novine, No. 158/03, 100/04, 141/06, 38/09, 123/11, 56/16.

[15] UNEP/MAP: State of the Mediterranean Marine and Coastal Environment, UNEP/MAP-Barcelona Convention, Athens, 2012.

[16] United Nations Convention on the Law of the Sea, Official Gazette of the Republic of Croatia - Narodne novine, Međunarodni ugovori, No. 9/00.

[17] Yincan, Y., et al: Submarine Optical Cable Engineering, Elsevier Academic Press, 2018

SWEDISH DRY PORTS' SERVICES

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Summary

The purpose of the study is to investigate which services of Swedish dry ports have the largest positive influence on stakeholders' criteria; in order to suggest a configuration of a dry port that brings the most benefits to the stakeholders. Multi-actor, Multi-Criteria Analysis method was used as a basis for the research; it allowed evaluation of different scenarios (sets of services available at dry ports) considering objectives and opinions of multiple stakeholders. Scenarios and criteria were identified by literature analysis.

The findings show that the basic services of the studied dry ports were crucial for establishing operations; however, further advancement of service portfolio by adding value-added services (VAS) and customer-oriented services keeps bringing extra benefits to the stakeholders both from financial and environmental points of view. Majority of Swedish dry ports keeps developing their service portfolio towards wider range of VAS and specific customized services according to their customers' and potential customers' demand.

Study is limited to the Swedish dry ports connected to the Port of Gothenburg by rail. The study focuses only on services and does not take into consideration other characteristics of the dry ports. The study contributes to the body of knowledge on dry port research by identifying the stakeholders' benefits from particular services available at the dry ports.

Keywords: Dry port, hinterland transport, logistics services, MAMCA, Sweden

1. INTRODUCTION

Seaborne transportation has been rapidly growing ever since popularization of containers. A need to cope with steadily increasing cargo volumes and capacity limitations of seaports resulted in developing new strategies to increase seaports' capacity. As the response to the lack of capacity at the seaports came the necessity to "move seaports inland" by developing hinterland transportation infrastructure and logistics. Other way round, regions located in the hinterland of seaports seek opportunities to develop and attract new business and investments; among others by development of inland facilities (see more for directional development of dry ports in [1]). Answering both needs, the hinterland development occurred in the form of hinterland transport infrastructure advancement and construction of inland intermodal facilities. Nowadays, various types of inland facilities serve to assist seaports that are seeking to cope with ever growing cargo flows. As the result, there are multiple alternatives available for shippers to transport cargo to/from hinterland. The opportunities range from direct road transportation between a seaport and shippers' facilities, to complex hinterland transportation solutions involving various types of inland terminals. At the same time, a choice of hinterland transportation has a strong tendency towards the least costly solutions see e.g. Henttu and Hilmola (2011) [2]. Therefore, given the multiple stakeholders involved in the hinterland operations, it is important to find out what is an optimal configuration of a dry port. Thus, the purpose of this study: to suggest a configuration of a dry port that brings the most benefits to the stakeholders; by finding out what services of the dry ports have the largest positive influence on stakeholders' objectives and whether there is an optimal configuration for all involved stakeholders.

2. FRAME OF REFERENCE

2.1. Dry port concept and services

Recent trend in transportation research suggest focus on not only cost-efficient, but on sustainable solutions, taking into consideration social, economic and environmental aspects. Answering this trend, the research on dry ports has emerged [3]. A dry port refers to an inland intermodal terminal directly connected to a seaport by rail, where customers can leave/pick up their standardized units, as if directly at the seaport [3]. Dry port concept is often referred as sustainable having a positive effect on sustainability components. Firstly, cost-efficient hinterland transportation by high-capacity transport modes (rail, inland waterways) compared to business-as-usual alternatives (road) brings economic benefits to the whole supply chain; ones the facilities are in place and the rail is electrified, the setup does not require significant investments, only operational costs that are comparatively low. Secondly, intermodal setup (hinterland transportation through a dry port) has lower environmental impact (especially if the rail is electrified; but also, in the cases with lower level of electrification due to scale advantages). Finally, development of dry ports stimulates regional development; i.e. investments come to the regions attracting new businesses, new work places are getting open.

The given above dry port definition suggests that there are two important elements of the dry port concept, namely: 1) high-capacity transport connection between the seaport and the dry port, and 2) a dry port is the seaport's interface inland where containers are handled the same way as they would be handled at the seaport. The first aspect, high-capacity transport connection, implies presence of infrastructure allowing efficient transport of consolidated cargo as well as frequent schedule and reliable transportation. Often the research on dry ports highlights the availability of rail infrastructure and rail shuttles as an element of dry port concept e.g. [4]–[8]. Some authors refer to inland waterways as to an alternative high-capacity transportation mean e.g. [9]–[11] but the same contradicts with the term "dry". Some, e.g. [12], [13], refer even to road transportation that in principle does not meet the requirements of a high capacity transportation mean which is the core aspect of the dry port concept. The second aspect, dry port as a seaport's interface inland, implies that the shippers/customers have an opportunity to handle their cargo at a dry port in the same way as if they would do it in a seaport i.e. that the typical to a seaport services are expected to be available at the dry port; this aspect is in focus of the current study.

Services availability, as well as other characteristics of dry ports are to some extent shaped by direction of development, seaports' specifics, connectivity and distance to the seaports, and development of the region and industrial activity in there [14]. Due to differences in these parameters, dry ports provide different types of services, and their number and range vary and change over time [15]. According to the authors, the service availability also depends on market characteristics; and the services are customized in accordance with the customers' needs and preferences. The services at the dry ports often develop over time starting from more basic and essential ones towards more specific to the customers' demands i.e. from loading/unloading, transhipment and storage to maintenance, warehousing, administration/customs, security, and towards customers' specific value-added services (VAS) such as e.g. kitting and sequencing [15], [16]. Wide spectrum of services allows a dry port to benefit from economy of scale and to minimize cost of the services (ibid). Services fall into categories of standard / basic services and VAS, thus some of them, the basic ones, e.g. rail transportation, transhipment, storage, and customs clearance, are essential at nearly any intermodal terminal [17]. Most of the services at dry ports are performed for the customers' convenience i.e. relevant to own needs the shippers/customers choose to use any of the service. Services that are typically listed among expected at different types of dry port are summarized in Table 1 based on the findings from the literature.

Table 1 Typical services at dry ports

Service	Source
Transhipment	[18], [19]
Storage	[18], [20]
Depot	[18]
Maintenance/repair of containers/wagons	[19]
Tracing and tracking	[18]
Customs clearance	[18], [20]
Warehousing	[15], [20]
Handling of empty and loaded containers	[19]
Forwarding	[19]
Consolidation	[21]
Transit	[15]
Handling of dangerous goods	[15]
Goods reception	[15]
Stuffing	[15]
Material control	[15]
Cross docking	[15]
Repacking and relabeling	[15]
Subassembly	[15]
Kitting and sequencing	[15]
Quarantine	[17]
Pre-assembly	[17]
Quality and inventory control	[17]
Road haulage	[17]
Online booking	[22]
Reefer plugs	[22]
Trailer lifts	[22]
Safe parking	[22]

3. CASE DESCRIPTION

The current study has a Swedish perspective; all of the inland intermodal terminals included in the study meet the above given definition of a dry port and have a rail connection to the Port of Gothenburg. The Port of Gothenburg has a vast network of so-called Railports: a system of rail shuttles connecting inland locations (terminals) with the seaport allowing efficient lifting up containers from the seaport as well as fast loading of export containers on the vessels. In 2018, 60% of the containers handled in the Port of Gothenburg were transported by rail (equivalent to appx. 451800 units) [22]. The list of 20 Railports served as a starting point for a selection of facilities that fit into concept of a dry port. Facilities having dry port characteristics were included in the study while those with low volumes, location on inland waterways, absence of regular rail shuttles were excluded and thus the initial list of 20 was reduced to 13 (table 2).

Table 2 Selection of dry ports

N	Included Railports
1	Eskilstuna Intermodal Terminal
2	Hallsbergsterminalen
3	Skaraborg Intermodal Terminal
4	Vaggeryd Logistic Center
5	Katrineholms Logistikcenter
6	Luleå Intermodal Terminal
7	Nässjö Intermodal Terminal
8	Stockholm / Årsta Intermodal Terminal
9	Sundsvall Intermodal Terminal
10	Umeå Intermodal Terminal
11	Gävle Intermodal Terminal
12	Insjön Combiterminal
13	Torsvik Intermodal Terminal

The final selection of 13 facilities having dry port characteristics was used for the data collection and analysis.

4. METHOD

4.1. Method choice

As per method, MAMCA is a method suitable for evaluation of different transport-related projects taking into consideration multiple criteria of multiple actors [23]. A search for the key word “MAMCA” at Science Direct database (conducted on 2 of July 2019) reverted in 85 results mainly related to urban transportation projects and associated policies [24], [25], but also other transport-related issues such as biofuel selection [26], infrastructure projects [27], [28], traffic and pedestrian flows design [28], sustainability of hinterland transportation [29]. MAMCA is a well-suitable method both for gathering relevant opinions before actual implementation of a project, but also after implementation as an evaluation tool [30].

4.2. Multi Actor Multi Criteria Analysis (MAMCA)

4.2.1. General description of MAMCA

Multi-actor, Multi-Criteria Analysis (MAMCA) is a method that is often applied to evaluate different transport-related projects [23]. MAMCA allows to evaluate alternatives by using multiple criteria defined for multiple stakeholders. The strength of the method is in its ability to include different stakeholders in the process of evaluation taking into consideration their objectives. The method rises awareness about stakeholders’ objectives among all concerned parties and about the possibilities to meet the objectives by choosing one or another alternative. The method makes the participants “to reflect on what they really want and on the rationality for these wants” [23]. In this study the method is used to evaluate different sets of services of dry ports in order to point out which of them have the largest effect on the stakeholders’ objectives and whether there is an optimal set of services at a dry port for the stakeholders [23]. The results obtained by application of MAMCA contribute to better understanding and agreement among the stakeholder groups regarding the question in focus [30].

4.2.2. MAMCA: step by step

There are seven steps suggested by MAMCA; and their "step by step" description is described in this chapter.

First step of MAMCA, Defining the Problem and the Alternatives, suggests identification of the problem and alternative solutions to the problem (scenarios) [23]. The scenarios (alternatives) can take different forms e.g. represent technological solution or different policies. In addition to the alternatives to be evaluated, a reference scenario can be introduced to allow evaluation in comparison to a "usual" solution. The method suggests to identify the scenarios based on relevant literature and with help of experts unless the alternatives are obvious (e.g. predefined by research conditions) [30].

Second step, Stakeholder Analysis, suggests identification and analysis of stakeholder groups and their objectives. Stakeholders are defined as people/company who/which "has an interest, financial or otherwise, in the consequences of any decision taken" [23], [30]. To meet the completeness requirement, the final list of the stakeholders should represent all relevant points of view (stakeholders) regarding the problem in question. If opinions within a stakeholder group are not homogeneous, the group should be divided into several groups and each of them should be analyzed separately. If the weights given to the criteria differ significantly among the representatives of the same stakeholder group, sensitivity analysis should be conducted [30]. Typically, the stakeholders are considered to be equally important and therefore they have equal weights (ibid).

The following third step, Defining Criteria and Weights, implies translation of the stakeholders' objectives into criteria. The method suggests that the criteria should be first extracted from the relevant academic literature and then validated by the stakeholders [30].

Step four, Indicators and Measurement Methods, suggests further detailing of the criteria to indicators that "… provide a 'scale' against which a project's contribution to the criteria can be judged" [23, p. 189]. Also, at this stage a suitable method for assigning weights should be chosen.

After all the elements are identified, the fifth step, Overall Analysis, that of actual criteria-scenarios relations evaluation, is performed. The evaluation can be conducted by analysts, experts or stakeholders [30]. Stakeholders' evaluation might lead to "lobbing" of one or another alternative, thus it is suggested to involve experts in the evaluation process (ibid).

Finally, step six, Results and Sensitivity Analysis, and seven, Implementation, are related to presenting results and suggestion regarding implementation of the scenarios. The results appear in the form of "classification of the proposed alternatives" [23]. For each stakeholder group the results show which services (scenarios) have positive and negative effect on the stakeholders' objectives. In other words, the results reveal "strengths and weaknesses of each option with regard to each of the stakeholder groups' concerns" [30]. In this way, the information obtained from evaluation process is expected to provide important insights and to stimulate better understanding among the stakeholders involved in the common business and its development. After identifying the best alternative, the next step is implementation.

In this research the method was adapted for the study purpose and extended by in-depth analysis of scenarios in order to provide more detailed results. The respondents were additionally asked to assign the weights to the criteria twice: first, in the beginning of the survey, and later on, after assessment of the criteria-scenarios relations, in order to identify whether the perception changed after putting more thoughts into evaluation.

4.3. Application of the MAMCA to the study

4.3.1. Defining the Problem and the Alternatives

The purpose of MAMCA application supported the purpose of the study: to investigate what services of dry ports have the largest positive influence on stakeholders' objectives. The scenarios were identified based on the literature review on dry ports and by studying the variety of the Railports (here: dry ports; inland intermodal terminals connected by rail to the Port of Gothenburg). The dry ports were studied and divided into categories relative to the type and amount of services they provide; in such way the scenarios were formulated (Table 3). The scenarios were then discussed with an expert from the Port of Gothenburg closely related to the operational work with the Railports. The expert agreed with the scenarios' definition (reference scenario with no dry ports in the hinterland transportation system; basic dry ports (scenario 1) towards more specialized (scenario 3)); a remarque was that the allocation of services between scenarios 2 and 3 might differ in real settings depending on dry port's customers portfolio. Overall idea of allocating services between the scenarios 2 and 3 is that the services are either related to handling of containers and available for wide range of shippers, or related to the cargo itself and available by demand for larger shippers.

Table 3 Scenarios

Scenarios	Service available at the dry port
Base-case scenario (business-as-usual (BAU)): All the services are performed at the seaport	No dry port in the system
Scenario 1: Essential / basic (standard terminal services) are available at the dry port	Transhipment
	Storage / depot
	Handling of empty and loaded containers
	Road haulage
Scenario 2: Extra VAS (available to any customer as VAS) are available at the dry port	Customs clearance
	Tracking and tracing
	Maintenance/repair of containers
	Forwarding
	Container consolidation
	Handling of dangerous goods
	Cross docking
	Online booking
	Reefer plugs
Scenario 3: Customer-oriented VAS (requested by specific customer) are available at the dry port	Warehousing
	Stuffing
	Material control
	Repacking and relabeling
	Subassembly
	Kitting and sequencing
	Quarantine
	Quality and inventory control
	Safe parking for trailers/trucks

4.3.2. Stakeholder Analysis

According to the method, stakeholder groups were identified by consulting academic literature e.g. by benchmarking studies conducted in similar settings (e.g. [29]). In addition to the dry ports, other stakeholders conducting operations through / having other interest in the dry ports, were selected (Table 4).

Table 4 Stakeholders involved in the study

Stakeholder	Description
Dry port operators	Operators running the dry port operations
Municipality/region of a dry port	Municipality / region where the dry port is located
Seaport	Maritime port (including authorities and terminal operators) connected to the dry port
Shippers	Cargo owners
Shipping lines	Operators that transport cargo by sea
Rail operators	Operators that transport cargo by rail
Road operators	Operators that transport cargo by road

The opinions within the stakeholder groups were considered homogeneous and thus the groups remained the same throughout the study; not any stakeholder group was divided into smaller groups for the analysis.

The data collection started with contacting all the pre-selected dry port; and the rest of the contacts was mainly obtained using snowballing technique by asking the dry ports' operators for recommendations. In this manner, most of the shippers and municipality representatives included in the study were identified. The other contacts were obtained in the same way or by search on the Internet.

Each stakeholder group is represented by at least one respondent which is sufficient according to the method. Dry port operators and some of the facilities were visited, which allowed deeper conversations and better understanding of the functionality of the dry ports. Municipality representatives contacted were those involved in establishing of the dry ports; thus, competent on the topic. The seaport is represented by the experts from the Port of Gothenburg due to the case limitations. The shippers are mainly represented by large retail companies with volumes sufficient for frequent cargo trains. The shipping companies were those directly involved in operations on transport legs connected to the Port of Gothenburg and/or inland locations.

4.3.3. Defining Criteria and Weights, and Indicators and Measurement Methods

The objectives of the stakeholder groups' were identified by literature search and analysis of the Swedish dry ports business; additionally, the interview transcripts from the case study on Skaraborg dry port were consulted to obtain more comprehensive picture.

After objectives were identified, an extensive list of criteria corresponding to them was gathered. Criteria that were frequently mentioned in the academic literature on dry ports formed the basis; the selection was strengthened by consulting separate body of academic literature focusing on stakeholders' objectives, and the list was transformed into a tree-structure of criteria and indicators. Finally, a pilot study was conducted to obtain experts' opinion whether the identified criteria and indicators were necessary and sufficient for the study. Consequently, the list was refined and reduced and only limited number of criteria and indicators remained for the data collection. The final list of the criteria and indicators is presented in the Table 5 (summary from the academic literature).

Table 5 Criteria and indicators

Stakeholders	Criteria and indicators
Dry ports	1. Profit
	1.1. Increase volumes
	1.2. Capacity utilization
	1.3. Attract new customers
	2. Green image
Dry ports regions/municipalities	1. Boosting regional economic development
	1.1. Job
	1.2. New business
	2. Environmental performance
	2.1. Traffic and congestion reduction
	2.2. Emission reduction
	2.3. Noise and vibration reduction
	3. Green image
Seaport (terminal operators and authorities)	1. Profit
	1.1. Volume increase
	1.2. Operational efficiency
	2. Competitiveness/competitive advantage
	2.1. Secure hinterland
	2.2. Expand hinterland
	2.3. Attractiveness for new customers (in foreland)
	3. Green image
Shippers (cargo owners, importers and exporters)	1. (Logistics) costs
	1.1. Transport costs
	1.2. Storage/warehousing
	1.3. Avoiding road tolls
	2. Service level
	2.1. Reliability
	2.2. Flexibility
	2.3. Improved seaport access
	3. Green image
Shipping lines	1. Profit
	1.1. Volumes increase (Increase of sales)
	2. Competitiveness
	2.1. Reduced complexity
	2.2. Control over services/landside operations
	2.3. Reliability
Rail carriers	1. Profit
	2. Competitiveness
	2.1. Attracting new customers in the serving hinterland
	2.2. Attracting new customers from the serving foreland
	3. Reliability
Road operators	1. Profit
	2. Avoiding congested roads
	3. Avoiding environmental zones

4.3.4. Overall Analysis and Results

The evaluation of criteria-scenarios relations was performed by the stakeholders; the proposed evaluation form allowed the respondents to evaluate the effect of each scenario on each criteria and/or indicator. The results of stakeholders' evaluation were analysed and discussed.

4.4. Data collection

In most cases phone interviews or face-to-face interviews combined with site visits were conducted, where apart of explaining nature of operations through/other interest in the dry ports and providing general information used for analysis, the actors were guided through MAMCA steps. To collect required data, the respondents were asked to do the following assessments: assign weights to the criteria and indicators, evaluate scenario-criteria relations, and to reconsider the weights if to be changed after evaluation.

First of all, the respondents were asked to assign weights to their criteria by allocating ten points among them; at this stage they had a chance to propose more criteria and indicators if in their opinion some were missing from the list. Secondly, respondents were asked to fill in the forms where they could numerically express their opinion of each scenario effect on each indicator or/and criterion by using the proposed scale (Table 6).

Table 6 The scale for criteria assessment

-5	-3	0	3	5
Strong negative effect	Negative effect	Neutral relation	Positive effect	Strong positive effect

In the settings of the study (i.e. significant geographical distances between the stakeholders and busy working schedules) it was practically challenging to organize a meeting for all the stakeholders involved in the evaluation in order to find a consensus, therefore a practical solution to derive a group preference was to aggregate data by using mathematical methods.

Same set of criteria was suggested for analysis within same stakeholder groups. Given the tree-structure of criteria and indicators, some criteria were assigned indicators whereas other criteria played a role of both a criterion and an indicator. Proposed indicators were of both quantitative and qualitative nature. In cases when criteria had indicators, the respondents were asked to evaluate the dependency of indicator-scenario relations, in other cases when the criteria were not detailed by indicators the respondents assessed criterion-scenario relations. In addition, due to the fact that the scenarios were dependent one on another i.e. each subsequent included the previous one, while the evaluation process the respondents were asked to compare each scenario to the previous one but not to the BAU scenario. The respondents used the scale presented in the Table 6; to translate grades to suitable ones for analysis, the grades were summed up.

Thirdly, the step of assigning weights to the criteria was repeated after criteria-scenarios relations evaluation was complete, in order to give the respondents a chance to rethink the values after more close consideration.

5. RESULTS

The study has multiple findings. Firstly, the study identifies stakeholders and their objectives in relation to the dry port operations (summary in the table 5). Secondly, the stakeholders' evaluation of those criteria shows the relative importance of the objectives (more details in the section 5.1). Thirdly, following the main purpose of the study, the optimal configuration of the Swedish dry ports is identified by applying MAMCA (more details in the section 5.2). Finally, existing Swedish facilities meeting the definition of the dry port are compared to the identified optimal configuration (more details in the section 5.3).

5.1. Evaluation of criteria importance

The table 7 presents allocation of weights averaged from responses of each stakeholder group. Each stakeholder group is represented by at least two respondents.

Table 7 Weights

Stakeholder groups / criteria and indicators	Initial	After reconsideration
1. Dry port		
Profit	6,67	6,50
Green image	3,33	3,50
2. Dry port's municipality		
Boosting regional economic development	5,50	5,50
Environmental performance	2,00	2,00
Green image	2,50	2,50
3. Seaport		
Profit	3,00	3,00
Competitiveness / competitive advantage	4,00	4,00
Green image	3,00	3,00
4. Shipper		
(Logistics) costs	5,00	5,00
Service level	3,00	3,00
Green image	2,00	2,00
5. Shipping lines		
Profit	3,00	3,00
Competitiveness	7,00	7,00
6. Rail operator		
Profit	6,00	6,00
Competitiveness	2,00	2,00
Reliability	2,00	2,00
7. Road operator		
Profit	7,50	7,50
Avoiding congested roads	1,50	1,50
Avoiding environmental zones	1,00	1,00

As the respondents had an opportunity to change the weights after the MAMCA evaluation there are two columns in the table 7. There are only small changes (if any) in the numbers, however, these changes have a similar pattern: increase of the importance of environmental aspect compared to pure financial benefits.

5.2. Results of MAMCA assessment

The overall result of MAMCA is presented in the figure 1. The BAU scenario was not evaluated by the respondents since some stakeholders could relate to the same, e.g. dry port as the stakeholder could not evaluate the effect of BAU scenario which means not having the dry port in the system. BAU was only used for evaluation of Scenario 2. Thus, there is no representation of the BAU scenario on the figure 1. However, some of the respondents reacted on BAU as being negative for their business. Overall, it is clear from the graph that there is a common perception that the scenario 3 is the one that has the largest positive influence on stakeholders' criteria.

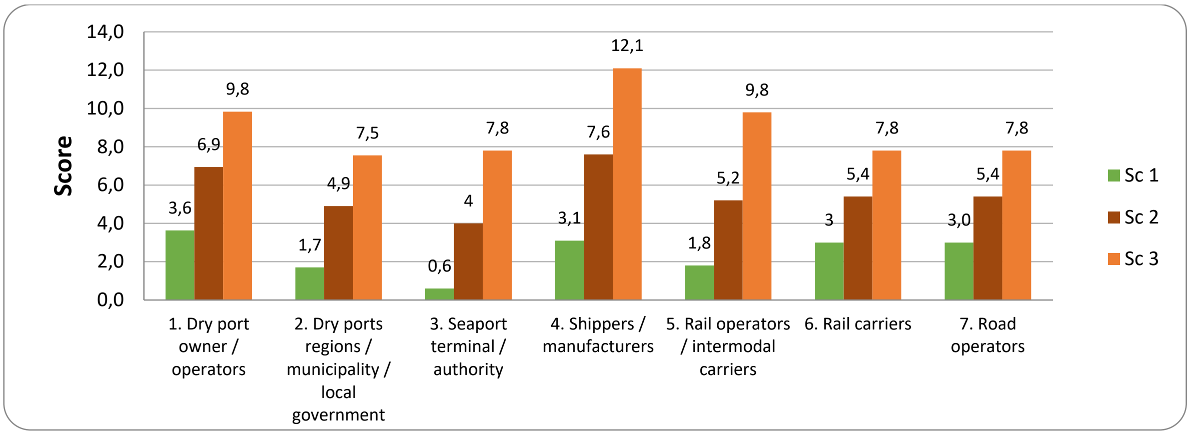

Figure 1 Overall result of MAMCA

Overall, the stakeholders prefer the scenario 3 which is the most advanced dry port with the most services available. Nevertheless, it is important to understand what each stakeholder groups' motivation is for preferring the scenario 3. From the table 7 it is obvious that the criteria directly linked to financial performance e.g. profit, logistics costs (for business players) are weighted on average higher compared to the other criteria. Seemingly, the scenario 3 has the most potential for reducing logistics costs and increasing profits.

The result of the weights assignment shows that the scenario 3 has the most positive effect on stakeholders' financial criteria. For example, dry ports increase their volumes by having more services by becoming a part of an attractive solution for wider range of customers. For example, according to one of the respondents from dry ports representatives, the service of quarantine (scenario 3) attracted a new shipper transporting natural bristle; this type of cargo had to undergo quarantine check for bugs. The seaport values the competitiveness criteria relatively more than pure profit, which is closely linked to volumes as well but at the end improvements in those areas lead to the profit. Similarly, this stakeholder group observes gradual improvement of financial objectives with advancement of dry ports' service portfolio. Same, for transport operators, the better choice of services makes the dry port integrated transport solution more attractive for cargo shippers and thus brings more business opportunities. From interviews with rail operators it is noted, that there are considerations for starting new trains on already existing and new routes connecting the Port of Gothenburg with the dry ports. Nevertheless, even scenario 1 is considered to be a valuable improvement by most of the stakeholder groups compared to the BAU scenario, except of the seaport group which evaluated the scenario 1 as rather neutral compared to the BAU one.

As for criteria related to environmental performance, the most of the stakeholder's groups observe improvement of the criteria with the improvement of service portfolio of the dry port, which contradicts an expected result. The most improvement of environment-related criteria was expected to be while shifting from BAU scenario to the scenario 1 when the largest modal shift between road and rail takes place. Scenarios 2 and 3 do not anymore bring much extra improvement to the same criteria, however, were perceived as having positive effect. For the case of municipalities, the environment-related criteria were rated the lowest due to the fact that consolidation of cargo and operations of dry ports do not reduce noise and pollutions in the region. Extra cargo trains have negative effect on noise pollution, however, severity of this compared to the BAU scenario (only truck operations in the region) should be measured separately.

5.3. Dry ports in Sweden

Based on the results the actual dry port facilities in Sweden were assessed (table 8).

Not all the facilities were reached to confirm their service portfolio. However, based on collected data it can be seen that all the studied facilities have full set of basic services. Regarding VAS and customer-oriented services, it differs from facility to facility. However, many services are available either straight at the dry ports location or can be organized in short term by own forces or with help of subcontractors. Few dry ports representatives reported that certain services were "not available for the moment" but should be added to the service portfolio in the future. Overall, service portfolio depends greatly on customers' demand, and if basic services (scenario two) are essential to establish dry port's, VAS and customer-oriented services support and develop the business and have a positive effect on all studied stakeholders' objectives.

6. CONCLUSION

Dry ports in Sweden play an important role in hinterland transportation and regional development. To ensure their operations, several stakeholders are involved. The results of the study suggest that there is an optimal configuration of a Swedish dry port that would allow to better reach objectives for all the interested parties, and that is the configuration that corresponds to the scenario 3 as defined in the study. The scenario 3 suggests that the dry port should provide different services ranging from the most basic ones i.e. transhipment, storage/depot, handling of empty and loaded containers, road haulage, to VAS and customer-oriented VAS. By expanding service portfolio dry ports become attractive for new customers, which in turn leads for expansion of operation. This is beneficial not only for the dry port operators, but for all the involved transport operators and the municipalities of the dry port location. For the latter, more operation in the region (if not necessarily brings new businesses to the area but) helps to retain the existing ones.

The comparison of the optimal configuration of a dry port to the current situation in Sweden shows that indeed all the dry ports provide the essential services (scenario 2) and vary a lot in regards of the services from scenario 3 and 4. This can be explained by close relation of the available services to what is demanded by the existing and potential shippers. It has been reported, that most of the "missing" services are also the ones that are never demanded. It has been also emphasised that even if smaller shippers request a particular VAS, it is likely to be provided by own forces or with help from subcontractors. At the same time, some of the services have been abandoned by the dry port due to low demand and high expenses to maintain them with no sufficient return.

The current study can be extended by more focused analysis of the services available and their influence on the stakeholders' objectives.

Table 8. Services available at the dry ports in Sweden

Service / Dry Port	Umeå	Vagerryd	Insjön	Eskilstuna	Katrine-holm	Årsta	Hallsbergs-terminalen	Skaraborg	Torsvik	Nässjö	Luleå	Sundsvall	Gävle
Transhipment	1	1	1	1	1	n/a	n/a	1	n/a	n/a	n/a	n/a	n/a
Storage / depot	1	1	1	1	1	1	1	1	1	1	1	1	1
Handling of empty and loaded containers	1	1	1	1	1	n/a	n/a	1	n/a	n/a	n/a	n/a	n/a
Road haulage	1	1	1	1	1	n/a	n/a	1	n/a	n/a	n/a	n/a	n/a
Customs clearance	0	1	0	1	0	1	1	1	0	0	0	0	0
Tracking and tracing	n/a	1	0	1	1	n/a	n/a	1	n/a	n/a	n/a	n/a	n/a
Maintenance / repair of containers	n/a	0	0	1	0	n/a	n/a	0	n/a	n/a	n/a	n/a	n/a
Forwarding	0	0	1	0	1	n/a	n/a	1	n/a	n/a	n/a	n/a	n/a
Container consolidation	1	1	1	1	1	n/a	n/a	1	n/a	n/a	n/a	n/a	n/a
Handling of dangerous goods	1	1	0	1	1	1	1	1	0	1	1	1	1
Cross docking	n/a	1	0	1	1	n/a	n/a	1	n/a	n/a	n/a	n/a	n/a
Online booking	1	0	0	0	1	0	0	1	0	0	1	1	0
Reefer plugs	1	1	0	1	1	1	1	1	0	1	1	1	1
Warehousing	1	0	0	1	1	n/a	n/a	0	n/a	n/a	n/a	n/a	n/a
Stuffing	1	1	1	1	1	0	1	0	0	1	1	1	1
Material control	0	0	1	0	1	n/a	n/a	0	n/a	n/a	n/a	n/a	n/a
Repacking and relabelling	1	0	0	0	1	n/a	n/a	0	n/a	n/a	n/a	n/a	n/a
Subassembly	0	0	0	1	1	n/a	n/a	0	n/a	n/a	n/a	n/a	n/a
Kitting and sequencing	0	0	0	1	1	n/a	n/a	0	n/a	n/a	n/a	n/a	n/a
Quarantine	0	1	0	0	1	n/a	n/a	0	n/a	n/a	n/a	n/a	n/a
Quality and inventory control	0	0	0	0	1	n/a	n/a	0	n/a	n/a	n/a	n/a	n/a
Safe parking for trailers/trucks	n/a	1	0	1	1	0	1	1	0	0	0	0	0

1 – service is available; 0 – service is not available; n/a – there is no information about availability of the service

REFERENCES

[1] G. Wilmsmeier, J. Monios, and B. Lambert, "The directional development of intermodal freight corridors in relation to inland terminals," *Journal of Transport Geography*, vol. 19, no. 6, pp. 1379–1386, 2011.

[2] V. Henttu and O.-P. Hilmola, "Financial and environmental impacts of hypothetical Finnish dry port structure," *Research in Transportation Economics*, vol. 33, no. 1, pp. 35–41, 2011.

[3] V. Roso, J. Woxenius, and K. Lumsden, "The dry port concept: connecting container seaports with the hinterland," *Journal of Transport Geography*, vol. 17, no. 5, pp. 338–345, 2009.

[4] R. Bergqvist and J. Woxenius, "The development of hinterland transport by rail - The story of scandinavia and the port of Gothenburg," *Journal of Interdisciplinary Economics*, vol. 23, no. 2, pp. 161–175, 2011.

[5] Z. Chang, D. Yang, Y. Wan, and T. Han, "Analysis on the features of Chinese dry ports: Ownership, customs service, rail service and regional competition," *Transport Policy*, Jul. 2018.

[6] J.-P. Rodrigue and T. Notteboom, "Dry ports in European and North American intermodal rail systems: Two of a kind?," *Research in Transportation Business and Management*, vol. 5, pp. 4–15, 2012.

[7] V. Roso, "Factors influencing implementation of a dry port," *International Journal of Physical Distribution & Logistics Management*, vol. 38, no. 10, pp. 782–798, 2008.

[8] V. Roso and D. Russell, "Adoption of the Dry Port Concept: a Diffusion of Innovation Assessment.," presented at the NOFOMA, Koldning, Denmark, 2018.

[9] C. Clott, B. C. Hartman, E. Ogard, and A. Gatto, "Container repositioning and agricultural commodities: Shipping soybeans by container from US hinterland to overseas markets," *Research in Transportation Business & Management*, vol. 14, pp. 56–65, Mar. 2015.

[10] H. Flämig and M. Hesse, "Placing dryports. Port regionalization as a planning challenge – The case of Hamburg, Germany, and the Süderelbe," *Research in Transportation Economics*, vol. 33, no. 1, pp. 42–50, 2011.

[11] T. Notteboom and Z. Yang, "Port governance in China since 2004: Institutional layering and the growing impact of broader policies," *Research in Transportation Business & Management*, vol. 22, pp. 184–200, 2017.

[12] A. K. Y. Ng, F. Padilha, and A. A. Pallis, "Institutions, bureaucratic and logistical roles of dry ports: the Brazilian experiences," *Journal of Transport Geography*, vol. 27, pp. 46–55, Feb. 2013.

[13] F. Padilha and A. K. Ng, "The spatial evolution of dry ports in developing economies: The Brazilian experience," *Maritime Economics & Logistics*, vol. 14, no. 1, pp. 99–121, 2012.

[14] L. C. Nguyen and T. Notteboom, "The relations between dry port characteristics and regional port-hinterland settings: findings for a global sample of dry ports," *Maritime Policy and Management*, vol. 46, no. 1, pp. 24–42, 2019.

[15] A. Bask, V. Roso, D. Andersson, and E. Hämäläinen, "Development of seaport-dry port dyads: Two cases from Northern Europe," *Journal of Transport Geography*, vol. 39, pp. 85–95, 2014.

[16] D. Andersson and V. Roso, "Developing dry ports through the use of value-added services," in *Commercial Transport*, Springer, 2016, pp. 191–203.

[17] V. Roso, D. Russell, K. Ruamsook, and G. Stefansson, "Seaport-inland port dyad dynamics: an investigation of service provisions and intermodal transportation linkages," *World Review of Intermodal Transportation Research*, vol. 5, no. 3, pp. 263–280, 2015.

[18] V. Roso, "Evaluation of the dry port concept from an environmental perspective: A note," *Transportation Research Part D: Transport and Environment*, vol. 12, no. 7, pp. 523–527, 2007.

[19] V. Roso and K. Lumsden, "A review of dry ports," *Maritime Economics & Logistics*, vol. 12, no. 2, pp. 196–213, 2010.

[20] J. Jeevan, S. Chen, and E. Lee, "The Challenges of Malaysian Dry Ports Development," *The Asian Journal of Shipping and Logistics*, vol. 31, no. 1, pp. 109–134, 2015.

[21] V. Roso, "The emergence and significance of dry ports: The case of the Port of Goteborg," *World Review of Intermodal Transportation Research*, vol. 2, no. 4, pp. 296–310, 2009.

[22] Port of Gothenburg, "Railport Scandinavia." 2019.

[23] C. Macharis, A. De Witte, and J. Ampe, "The multi-actor, multi-criteria analysis methodology (MAMCA) for the evaluation of transport projects: Theory and practice," *Journal of Advanced transportation*, vol. 43, no. 2, pp. 183–202, 2009.

[24] B. Kin, S. Verlinde, K. Mommens, and C. Macharis, "A stakeholder-based methodology to enhance the success of urban freight transport measures in a multi-level governance context," *Research in Transportation Economics*, vol. 65, pp. 10–23, Oct. 2017.

[25] P. Lebeau, C. Macharis, J. Van Mierlo, and M. Janjevic, "Improving policy support in city logistics: The contributions of a multi-actor multi-criteria analysis," *Case Studies on Transport Policy*, vol. 6, no. 4, pp. 554–563, Dec. 2018.

[26] L. Turcksin *et al.*, "A multi-actor multi-criteria framework to assess the stakeholder support for different biofuel options: The case of Belgium," *Energy Policy*, vol. 39, no. 1, pp. 200–214, Jan. 2011.

[27] M. De Luca, G. Dell'Acqua, and R. Lamberti, "High-Speed Rail Track Design Using GIS And Multi-Criteria Analysis," *Procedia - Social and Behavioral Sciences*, vol. 54, pp. 608–617, Oct. 2012.

[28] L. Vermote, C. Macharis, J. Hollevoet, and K. Putman, "Participatory evaluation of regional light rail scenarios: A Flemish case on sustainable mobility and land-use," *Environmental Science & Policy*, vol. 37, pp. 101–120, Mar. 2014.

[29] R. Bergqvist, C. Macharis, D. Meers, and J. Woxenius, "Making hinterland transport more sustainable a multi actor multi criteria analysis," *Research in Transportation Business & Management*, vol. 14, pp. 80–89, 2015.

[30] C. Macharis and G. Baudry, *Decision-Making for Sustainable Transport and Mobility: Multi Actor Multi Criteria Analysis*. UK: Edward Elgar Publishing Limited, 2018.

MARINE DIESEL ENGINES INJECTION PUMPS VIBRATION DIAGNOSTICS SUPPORTED BY MODELLING

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Summary

The article presents results of diagnostic and model vibration tests of ship diesel engines working with injection pumps in various technical states. There are presented the simulation and validation tests results. Presented results confirm the ability to apply the vibration method supported by a mathematical model in technical diagnostics of fuel installations.

Keywords: marine engines; vibrations; diagnostic.

1. INTRODUCTION

All working machines, also those in good technical condition, are a source of vibrations as a form of dissipated energy. In the vast majority of cases (but not always, for example, vibrations caused by the flow of the medium), they can be linked to periodic phenomena occurring in the machine, e.g., a rotating shaft, gear teeth or frequency of supply voltage in electric machines. Usually, the relationship between values and magnitude and/or phase of their occurrence is relatively simple do determine. From the point of view of vibration diagnostic it is useful and serves to fast assess the technical condition of the tested device.

Taking into consideration many years of experience gathered at the Institute of Construction and Operation of Naval Vessels, an analysis of the occurrence of operational incapacity of marine engines operated in Polish navy was carried out - Figure 1. The conducted analysis presented that the most common defects occur in the following functional systems [6]:

- engine fuel supply system - 72%,
- timing system - 19%,
- engine power supply system - 9%.

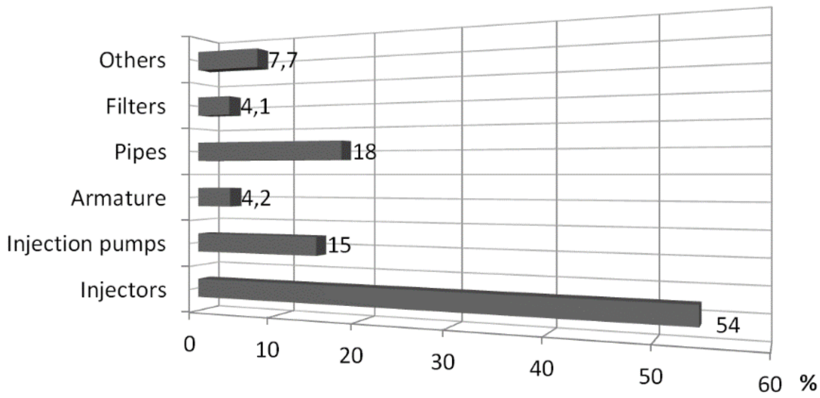

Figure 1 Percentage contribution of failures to individual elements of the fuel installation [6]

From the diagnostic point of view, exceeding the permissible values typifying the operation of fuel systems of marine diesel engines has two main consequences:

- leads to changes in mean effective pressure value in the engine cylinder (Fig. 2),
- changes in pressure distribution as a function of crankshaft angle (CA).

The paper is focused on the subject of vibration diagnostics of injection pumps because although their failures do not constitute the largest percentage their identification can be considered as the most difficult. On small vessels (particularly naval vessels), there are no portable stands for testing injection pumps, unlike stands for injector testing.

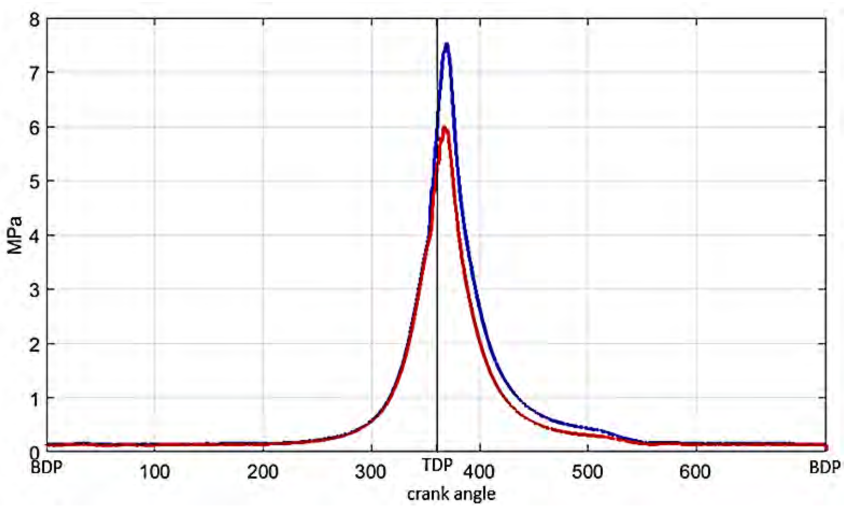

Figure 2 An example of the course of pressure changes in the cylinder of the Sulzer AL 20/24 engine working with efficient (blue line) and damaged injection pump (red line)

Changes in the technical condition of the fuel system could cause a decrease in the quality of the inside cylinder processes. Additionally, in the long term, can cause serious secondary damage to other components of the naval power unit, such as turbochargers, flexible couplings or torsional dampers. It is the reason why early detection of changes in the technical condition of injection pumps can also prevent secondary failure to other components of the propulsion system. Currently, the best method to accurately indicate the reason of disturbances in inside cylinder pressure is the indication procedure. In many cases, it cannot be made due to the lack or failure of indicator valves. The analysis of the literature gives the information that issues related to the vibration diagnostics of diesel propulsion engines, have not found a clear and acceptable methodology. Despite the inability to indicate, it is advisable for the personnel to have diagnostic information from other sources [7,8,11,12] In view of the above, an important issue is the selection of measurement optimal method and analysis of vibration signals to determine the technical condition of injection pumps of the marine engines.

2. THE COURSE OF RESEARCH

Gas pressure pulsation in the cylinder will result in a change of force affecting its crank-piston mechanism and the surfaces closing the combustion chamber [3,4,10]. Therefore, it can be assumed that the vibration parameters recorded in the immediate vicinity of the cylinder operating with the faulty injection system will differ from the reference condition [4]. At the initial stage of the study to determine the diagnostic sensitivity, the comparison of the amplitude spectra of the vibration accelerations obtained from measurements carried out at various points of the engine was made. On this basis, two measuring points located in two mutually perpendicular directions V (vertical) and H (horizontal) have been selected as the most susceptible to changes in the indicated pressure - Fig. 3. The substantiation is, the distribution of the main forces occurring in the crank-piston mechanism of the working diesel engine, what is presented. After performing the analysis of the suitability of the recorded vibration parameters, a further part of the tests was conducted only in relation to the vibrations recorded in the measuring axis V.

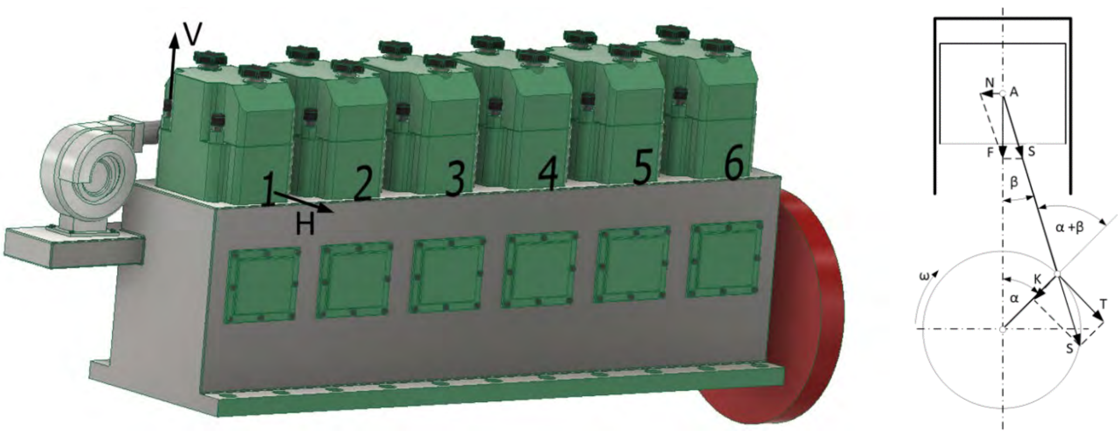

Figure 3 A simplified model of the 6 AL 20/24 engine with measurement axes (V, H) and force distribution in the crank-piston mechanism

During all stages of the research, vibration parameters were measured on subsequent heads of individual cylinders. Measuring points in the direction V (fig 3) were located on the tightening bolts of individual cylinder heads.

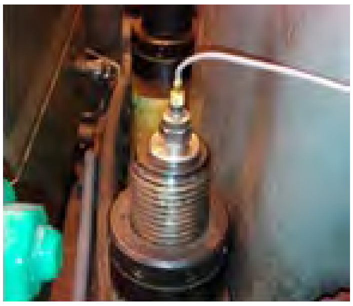

Figure 4 An example of accelerometer assembly on the Sulzer tightening bolt - direction V

The measurements were carried out in three stages corresponding to various technical states of the injection pump. The simulation of a change in the technical condition of the injection pump was gained by changing the pressure in the injector supply pipe. This change was obtained by adjusting the overflow screw on the pump discharge side. In order to determine the effect of the position of the overflow screw on the amount of fuel injected into the combustion chamber, cylinder pressure was continuously indicated - Fig. 2. During the first stage of the tests, vibration parameters of all cylinders were measured in a state of full technical efficiency, the results obtained as a reference during this stage served as reference. The next step was to take measurements with the injection pumps of individual cylinders switched off, which resulted in the simulation of the misfiring. During the last phase, the measurements were carried out for partial condition of individual injection pumps. The amount of fuel was reduced to the level at which the indicated pressure reduction was obtained by about 20% compared to the operation of a cylinder with a fully efficient injection pump. All stages of the tests were carried out in similar atmospheric conditions and for the same engine torque loads.

3. MARINE DIESEL ENGINE VIBRATION SIMULATION MODEL

At the same time, a simplified model of the tested engine dynamics in MatLab was developed. The main source of vibration excitations in working engine is rapid pressure changes occurring during the working stroke [1,2,10]. Therefore, when designing the model it was necessary to mathematically describe the course of pressure changes in individual engine strokes. Analyse of literature gives us information about many different diesel engine models, but usually, they are difficult to implement in the final engine vibration model [3,7,8,10]. In order to create a simplified pressure model according to the Sabathe theoretical cycle, it is necessary to determine the characteristic parameters of the engine cycle [2,5]: p_d- boost pressure, p_w - exhaust pressure, ε - compression ratio, n_1 – compression polytrope exponential index, n_2 - expansion polytrope exponential index, φ_c- pressure increase ratio, ρ - volume increase ratio, r - crank radius, λ - crank radius to the connecting rod length ratio, D - cylinder diameter, ω - crankshaft angular velocity.

To create a simplified model, it was assumed that in the intake stroke (in the range from 0 to 180° CA) the gas force acting on the piston remains constant and takes the value specified by the formula [2]:

$$F_g = \frac{\pi D^2}{4}(p_d - p_0) \tag{1}$$

where: p_0 - ambient air pressure.

In the next, compression stroke (180 to 360° CA), the change in gaseous force might be described by the equation

$$F_g = \frac{\pi D^2}{4}\left\{p_d\left[\frac{2\varepsilon}{(\varepsilon-1)(1-cos\varphi+0{,}5\lambda sin^2(\varphi))+2}\right]^{n_1}\right\} \tag{2}$$

In the work stroke (from 360 to 540° CA), the value of gas force will change approximately according to the dependence:

$$F_g = \frac{\pi D^2}{4}\left\{p_d\varphi_c\varepsilon^{n_1}\left[\frac{2\rho}{(\varepsilon-1)(1-cos\varphi+0{,}5\lambda sin^2(\varphi))+2}\right]^{n_2}\right\} \tag{3}$$

The approximate value of the gas force in the exhaust stroke (540 to 720° CA) can be considered as constant and described by the equation:

$$F_g = \frac{\pi D^2}{4}(p_w - p_0) \tag{4}$$

In diesel engines, the initial phase of the expansion stroke is an isobaric increase in volume and in this phase the formula (3) does not apply. According to the literature [2] this formula can be used. The condition is to replace the gaseous forces greater than those induced by the theoretical maximum pressure *p* with the forces corresponding to this pressure. The maximum pressure is expressed by:

$$p_z = p_d \varphi \varepsilon^{n_1} \tag{5}$$

In contrast, the gas forces caused by this pressure are described by the equation:

$$F_g = \frac{\pi D^2}{4}(p_z) \tag{6}$$

The substitution should occur in the range from 360 to φ_k °CA, where φ_k is given by the equation:

$$\varphi_k = arccos \frac{\sqrt{1 + 2\lambda(1 + 0{,}5\lambda - 2\frac{\rho - 1}{\varepsilon - 1}}}{\lambda} \tag{7}$$

As a result of the implementation of the presented equations and basic dimensions and masses of the Sulzer 6AL 20/24 engine to the MatLab script, the course of cylinder pressure changes shown in Figure 5 was obtained.

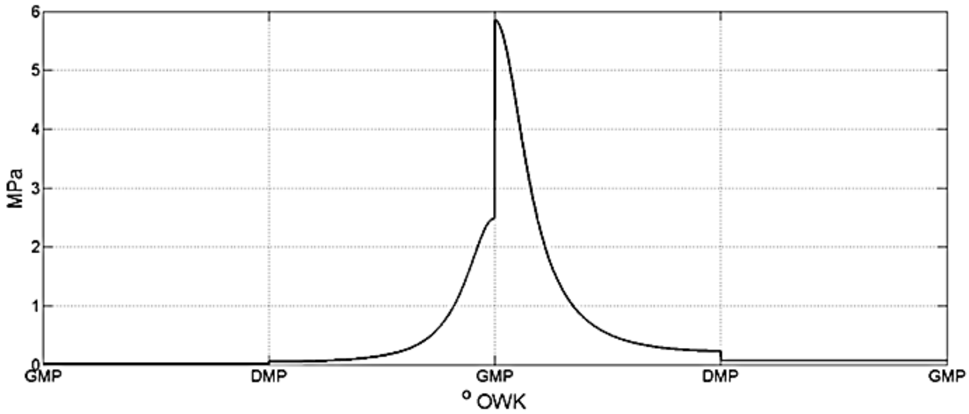

Figure 5 Changes in indicated pressure obtained as a result of modelling

Such a chart of pressure is unusable for further create a diesel engine vibration model due to step changes in pressure at the ends of each stroke. Therefore, the authors used one of the nonparametric methods of regression, i.e. weighted local-polynomial regression (*loess* - locally weighted scatterplot smoothing). As a result of applying the *loess* function to the course presented in Figure 5, a course much closer to the recorded during the engine's indication was obtained. The comparison of the three real curves obtained from the model and obtained from the model using the *loess* function was shown in Figure 6.

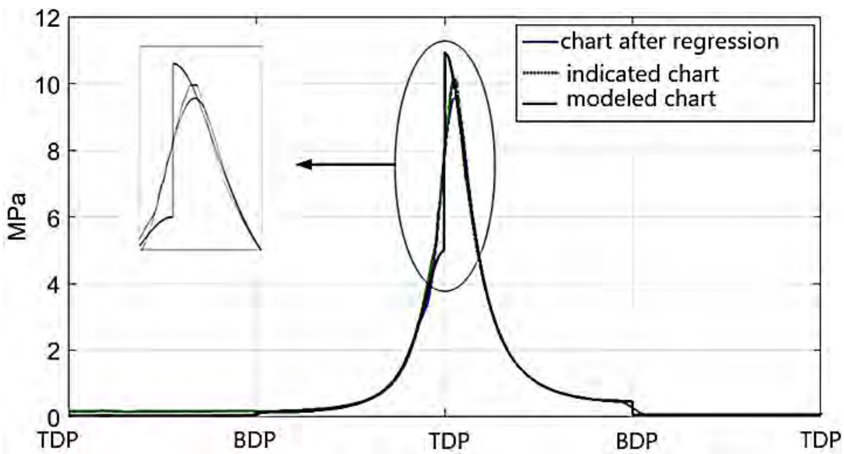

Figure 6 Comparison of the course of pressure changes obtained by three different methods

In order to determine the conformity of the cylinder pressure course obtained by modelling with the course recorded during the engine's indication in the first stage, the Pearson's linear correlation function was used (the dimensions of both matrices are identical). The analysis was carried out using the *crosscoef* procedure. The correlation coefficient of two variables describes their linear dependence taking values from -1 to 1. If both variables are N-length then the Pearson's linear correlation coefficients take the form:

$$r_{AB} = \frac{1}{N-1}\sum_{i=1}^{n}\overline{\left(\frac{A_\iota - \mu_A}{\sigma_A}\right)\left(\frac{B_\iota - \mu_B}{\sigma_B}\right)} \qquad (8)$$

Where μ_A and $\sigma_A$are the mean and standard deviation of the set *A*, while μ_B and σ_B are the mean and standard deviation of the set *B*. The linear correlation coefficient can also be calculated using the covariance function:

$$r_{AB} = \frac{cov(A,B)}{\sigma_A \sigma_B} \qquad (9)$$

After applying the *corrcoef* function, a correlation matrix with the following form is obtained:

$$\begin{bmatrix} r_{AA} & r_{AB} \\ r_{BA} & r_{BB} \end{bmatrix}$$

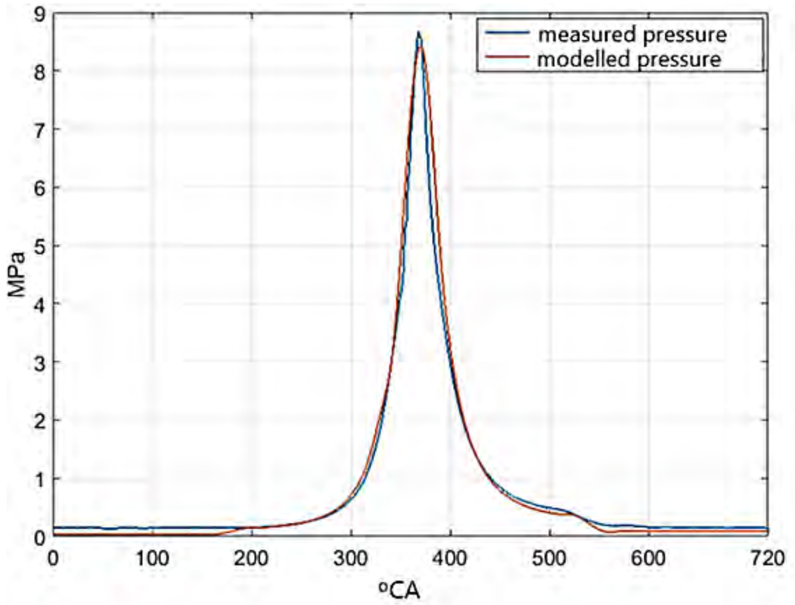

Figure 7 Indicated and modelled cylinder pressure course for an efficient engine operating at 750 rpm with a load of 3,3 kNm

The following values were obtained for the test runs shown in Figure 7:

$$\begin{bmatrix} 1 & 0{,}952 \\ 0{,}952 & 1 \end{bmatrix}$$

The obtained results confirm a very strong linear relationship between the indicated pressure course recorded during test stands and the course obtained from the simulation model.

In the developed engine dynamics model, the firing order was taken into account as well as the distribution of forces in the crank-piston mechanism, also the forces related to the operation of suspended mechanisms were included. The implementation of the obtained pressure model for the engine dynamics simulation model allowed to generate modelled time courses of vibration accelerations for various engine operating states. The comparison of the model chart (in relation to the efficient engine) and the chart recorded on engine's cylinder no. 1 is shown in Figure 8 and 9.

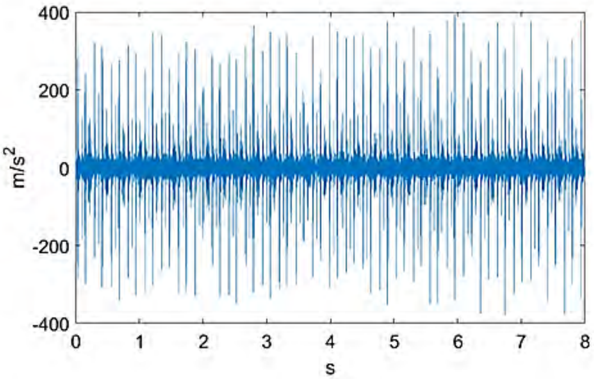

Figure 8 Vibration accelerations obtained during measurements on the real object

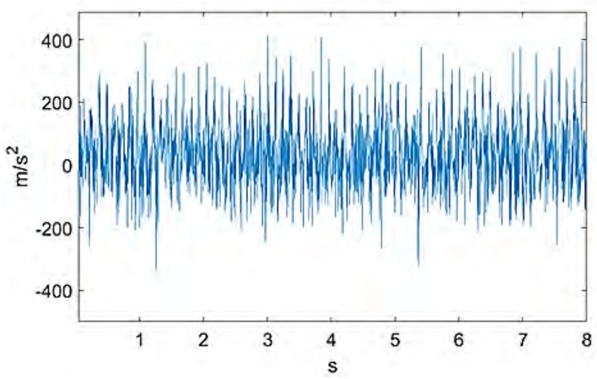

Figure 9 Vibration accelerations obtained on the way of modelling

4. RESULTS

Using the Fourier's, the recorded time courses was switched from time to frequency domain. The obtained waveforms were subjected to a comparative analysis for changes in amplitude values that may be related to the technical condition of individual cylinders injection pumps. The reference courses were vibration acceleration waveforms recorded on a test stand during fully technical efficient engine operation.

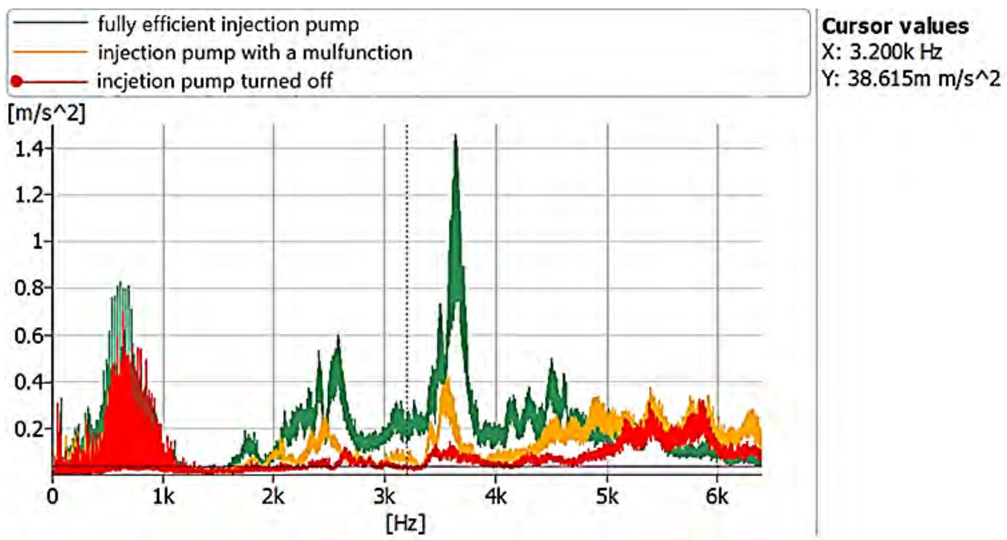

Figure 10 Acceleration vibration amplitude spectra of the SULZER 6AL 20/24 engine cylinder no. 1, recorded in the direction V for a rotational speed of 750 rpm and a load of 3,2 kNm

On figure 10, the green colour line indicates the reference spectrum of engine vibration acceleration, orange colour line refers to the engine working with partially efficient injection pump on a cylinder which the accelerometers were mounted. Red spectra were recorded after turning off the injection pump. It is seen that switching off the injection pump caused a significant reduction in the amplitude values in the whole measuring range. Similar results were obtained by switching off the injection pumps of the remaining cylinders of the tested engine. It allows forming the conclusion that ignition misfires are relatively easily detectable using vibration methods. Which is why in the next part of the work was focused on determining the possibility of detecting the initial stages of the inefficiency of injection pumps. Simulated damage to the injection pump consisting in reducing the amount of fuel injected into the combustion chamber caused a decrease in amplitude in the higher frequency range (above 1,5 kHz), however, it is not as clear and repetitive as in the case of misfires. This was the reason for looking at symptoms that could determine the technical condition of the injection pump in the low frequency range. Characteristic frequencies resulting from the principle of operation and construction of the tested engine were selected. They were marked in Figures 11 – 14 and indicated in Table 1. At the same time, values of amplitudes obtained during measurements and as a result of engine vibration modelling were carried out. Slight differences in frequency values result from the engine governor principle of working. It follows that the actual rotational speed of the engine crankshaft oscillates slightly around the speed set by the user. In the case of results obtained from the model, the frequency values do not differ because a constant rotational speed of 750 rpm was applied.

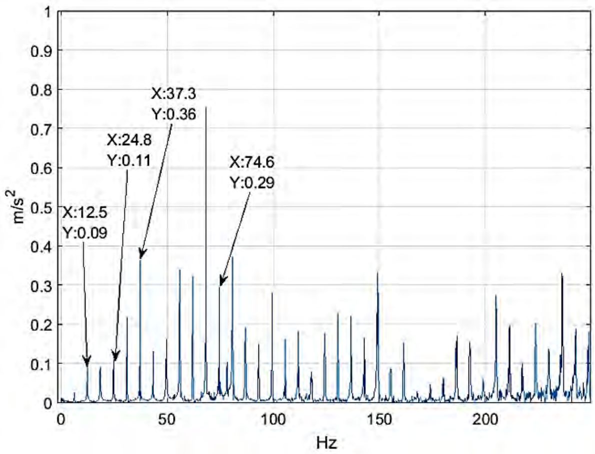

Figure 11 Acceleration vibration spectra of the cylinder no. 1 of the efficient 6 AL 20/24 engine at the rotational speed of 750 rpm for the real object

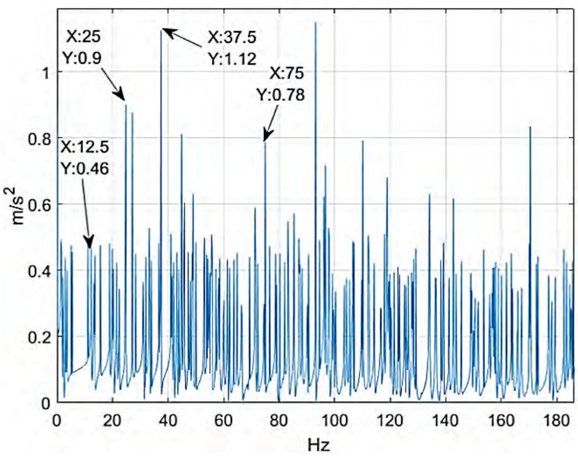

Figure 12 Acceleration vibration spectra of the cylinder no. 1 of the efficient 6 AL 20/24 engine at the rotational speed of 750 rpm obtained as a result of modeling

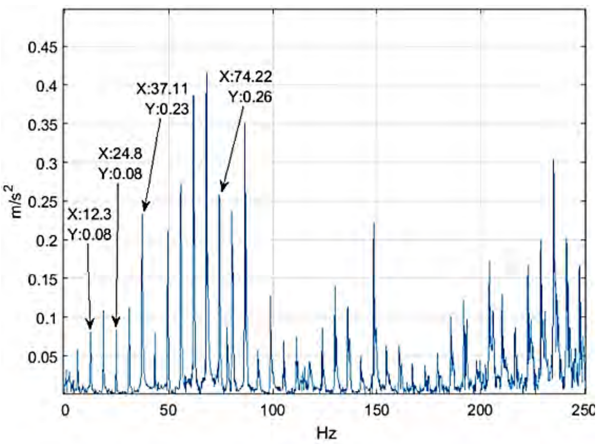

Figure 13 Acceleration vibration spectra of the cylinder no. 1 of the engine 6 AL 20/24 working with the damage of the injection pump cylinder No. 1 for the rotational speed of 750 rpm - real object

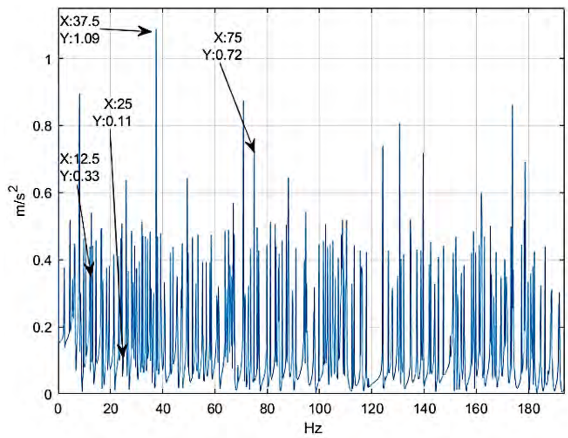

Figure 14 Acceleration vibration spectra of the cylinder no. 1 of the engine 6 AL 20/24 working with the damage of the injection pump cylinder No. 1 for the rotational speed of 750 rpm - result of modelling

Table 1 Comparison of the values of vibration accelerations measured and simulated for the vertical direction V - cylinder No. 1

	I harmonic a [m/s²]	II harmonic a [m/s²]	III harmonic a [m/s²]	VI harmonic a [m/s²]
Measured – efficient engine	0.09	0.11	0.36	0.29
Simulated – efficient engine	0.46	0.9	1.12	0.78
Measured – injection pump malfunction cyl. 1 .	0.08	0.08	0.23	0.26
Simulated – injection pump malfunction cyl. 1	0.33	0.11	1.09	0.72

Table 1 presents the results obtained from measurements and modelling one of the tested engine cylinders from. The results achieved for the other cylinders show the same tendency. Analysis of collected data recorded during operation of the 6AL 20/24 engine with simulated failure of the injection pumps allowed to state that in the case of failure to the injection pump of a given cylinder, consisting in reducing the amount of fuel supplied to the combustion chamber, the vibroactivity of this cylinder is reduced. The same dependencies were obtained by modelling. The developed model requires further tuning to achieve greater adequacy.

5. CONCLUSIONS

The research results presented in the paper confirm that there is a strong relationship between the technical condition of marine medium and high speed marine diesel engines injection pumps and vibration parameters recorded on the engine heads. In addition, it is possible to indicate diagnostically sensitive parameters with simulations. The use of only vibration diagnostics limits the possibility of full identification of changes in the technical condition of injection system. Obtained results will be used to develop the proposed diagnostic method through the use of multi-symptom diagnostics methods. This step will enable identification of the original symptoms of changes in the technical condition of the fuel injection system in a non-invasive manner in the field of all rotational speeds and operational loads of marine diesel engines.

REFERENCES

[1] Burdzik R., Pankiewicz J.,Wądołowski, M. Analysis of bending-torsional vibrations for diagnostics of the crank system, Diagnostyka, 2016, Vol. 17, no. 4, pp. 79-84

[2] Iskra A., Dynamics of crnak-piston mechanisms of internal combustion engines, Publisher of Poznan University of Technology, Poznan, 1995 [in polish]

[3] Kluczyk M. An analysis of the kinematics and dynamics of a shaft-piston system in a single cylinder four-stroke engine ZS, Scientific Journal of Polish Naval Academy, R.(55), nr 3 (198), s. 51-62, 2014

[4] Kluczyk M., Grządziela A. High and medium speed marine diesel engines injection installation vibration diagnostic, Diagnostyka, vol. 18, no. 2, s. 37-42, 2017

[5] Komorska I., Modeling of Vibration Signal for Reciprocating Engine Diagnostics, Diagnostyka, 2(50), 2009

[6] Lus T., Łutowicz M., Marine diesel engines diagnostics, Research papers of Lithuanian University of Agriculture, vol 42, no 2-3, 141 – 149, 2010

[7] Mihanović L., Komar I., Gržan M., Methodology Analysis Using Exploitation Reliability with the use of the RTOP Main Diesel Engine. “Naše more” 63(2)/2016., pp. 48-55, doi 10.17818/NM/2016/2.2

[8] Mrzljak V., Medica V., Bukovac O., Simulation of a Two-Stroke Slow Speed Diesel Engine Using a Quasi-Dimensional Model, Transactions of FAMENA, Vol. 40, No. 2, 2016

[9] Pankiewicz J, Deuszkiewicz P, Dziurdź J, Zawisza M. Modeling of powertrain system dynamic behavior with torsional vibration damper, Advanced Materials Research Vol. 2014; 1036: 586-591.

[10] Radica G. Antonić R. Račić N. Engine Working Cycle Analysis for Diagnostic and Optimisation Purposes, Brodogradnja Vol. 60, No. 4, 2009.

[11] Zawisza M., Diagnosing mechanical damages not detected by the OBD system of diesel engines, Journal of Vibroengineering Volume:19, Issue:3 Pages: 1833-1844, 2008

MARINE FRESH WATER GENERATOR PROCESS OPTIMIZATION

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Summary

The introductory part of this paper offers an overview of approaches to the management of marine fresh water generator and points out the most important factors that influence the processes. The second chapter deals with operation and overhaul times influenced by evaporation intensity. Comparison is made of two modes of operation, and simple calculation as suming days in voyage and hours necessary for overhaul is also made. Third chapter gives an insight to the optimal management system for one single-stage unit. The suggested management system is based upon the energy balance equation also given in the chapter. In the fourth chapter analysis of most important operational values is made. The changes recorded on the six channel plotter are used to evaluate the suggested management system. The paper gives an example of optimal management system for the single stage fresh water generator and suggests further research.

Keywords: energy balance, management system, marine fresh water generator, optimization

1. INTRODUCTION

Although the process of fresh water production by distillation method is well known and analyzed in the scientific journals, significance of the distillation plant on board ship gives an opportunity for further improvement [1, 2].

Scientific results could be used to improve the management system and, as a consequence to reduce the price of the produced water or to improve its quality or both. Since on board ships waste heat is mainly used with the exception of small consumption of the electric energy for the sea water and distillate pumps, the price of production is the price of crew members working hours consumed for occasional cleaning and the price of expendable material used for cleaning [1, 2]. Used material is mainly acid solution used to dissolve scale created on the evaporator surfaces during operation hours.

The efficient management system [3, 9, 10] of the distillation process should increase the maximum continuous capacity and to decrease operation costs. It would be time consuming to engage engine room officer to manage the process of distillation, so it is clear a management system has to be implemented to achieve those tasks.

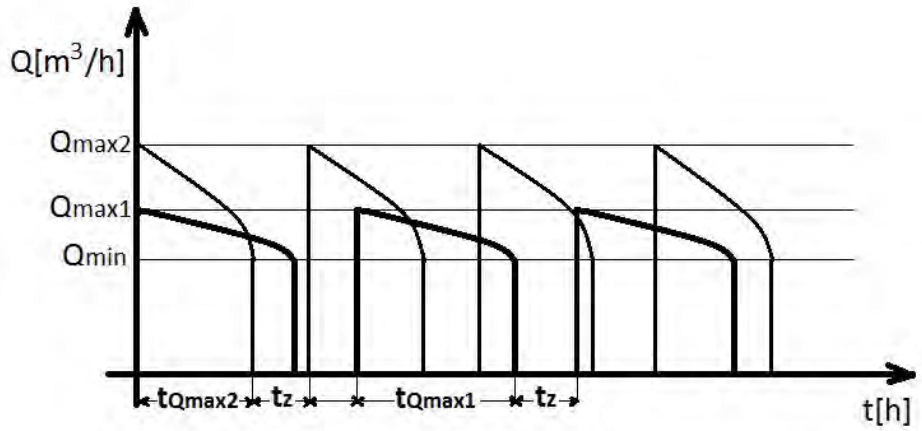
The process analysis, the analysis of thermodynamic parameters, the analysis of measured and regulated values [1, 2, 3, 4, 9, 10] point out the following:

- although the evaporator heat inlet and the condenser heat outlet change in time, by fixing the regulating valves position both of them could be considered constant
- with the above presumption the quantity of produced vapor and consequently of produced distillate depends mainly on pressure changes in the vessel, i. e. upper and lower values of pressure switch that opens and closes the vacuum breaking valve
- almost every measured parameter shows sinusoidal change exactly in accordance with the change of pressure, or precisely vacuum in the vessel, but some show deterioration with operating hours
- both short and long term changes in the process affect the quantity and quality of the distillate.

The managing algorithm should use above listed facts, but much more, especially fault propagation through the process [11, 12, 13, 14].

2. HOW THE OVERHAUL TIME AFFECTS THE CAPACITY

The diagram shown on graph 1 represents the changes in the capacity of the plant with the operating hours and the capacity maximum set point. The diagram stands for the single stage vacuum plant that could be found on almost every ship having diesel engine propulsion. There are three important elements such plants have: evaporator, demister and condenser, and several auxiliary elements or subsystems: brine rejection, vacuum management and distillate collection including the salinity check. Some technological differences are possible. Occasionally, plants could have only one ejector instead of two, while in some cases sea water is preheated being the condenser's cooling fluid. On the steam turbine propulsion ships not vacuum, but low or even medium pressure plants are used. In case large capacities are needed multistage plants are used. Those differences don't change the process basics.



Graph 1 The capacity and the operation hours of the distillation plant dependence

The qualitative changes shown on the figure perhaps aren't precise enough, but for the exact quantitative relations waste number of ship plants should be analyzed. Nevertheless the validity of obtained data could be questionable, because it depends on a number of factors. On the period during which desired and set plant's capacity is decreased to the lowest one, the one that still satisfies actual consumption, following factors are of importance: construction characteristics of the evaporator and condenser and their condition according to the exploitation, surrounding condition, i. e. sea water temperature, heat inlet and outlet settings, vacuum settings in the vessel and other. The longitude of the nonoperational period is affected by the scale thickness on evaporator surfaces, the quantity and concentration of acid solution applied, capability and training of crew members and other. The nonoperational periods during sailing through contaminated coastal waters are not considered, but the periods necessary for scale removal from heating surfaces are.

With all restrictions diagram on fig. 1 has, it could be useful for certain distillation process management system functions considerations. The diagram shows two distinct modes of operation: first, when lowest capacity is set, and second, when maximum obtainable capacity for given surrounding conditions and plant's operating condition is set. In both scenarios there is a small drop in capacity caused by scale formation on the heating surfaces, the difference being faster scale formation in the second scenario.

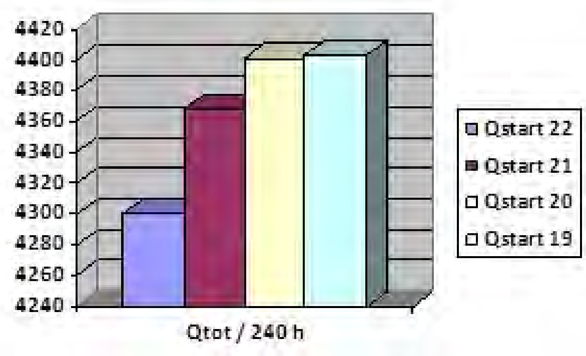
Why scale is formatted 'faster' and 'earlier'? 'Faster' means that its thickness is increased faster, while 'earlier' means at a lower point of a vertical channel. In the second scenario more heat is introduced in the process of evaporation or a high vacuum is created in the vessel, hence the temperature of sea water undergoing process of evaporation is higher, vapor bubbles are created on lower position in the evaporator channel, more vapor bubbles are created usually combining in a few larger ones, a very narrow brine layer with increased salinity remains on the surface wall [1- 8, 15].

Because of several reasons mentioned earlier in the paper, it's impossible to predict exact number of operating hours, but from marine practice it's known that in tropical environment having higher temperatures where larger amount of water is consumed and obviously higher production is needed, evaporator surfaces have to be cleaned every 48 to 72 hours, while in moderate climates this should be done only every few days.

Hence, although the increase in evaporation results with immediate increase of distillate production, because of often stoppages needed for cleaning the evaporator surfaces, the process production is in fact decreased. Sometimes the maximum production is necessary, but in most of cases more meaningful is that long term, process production that calculates both the production and stoppage periods.

Several practical situations will be compared. Fresh water generator with maximum capacity of 22 t/h is selected for analysis. The minimum capacity that satisfies ship's need is 18 t/h. Assumed voyage time on open sea is 10 days or 240 hours. In the first case operation starts with maximum capacity, it drops to minimum allowable capacity during 48 hours, and stoppage for cleaning that lasts for 6 hours follows. The second case starts with 21 t/h, it drops to minimum during 56 hours, and a stoppage for 4 hours follows. In the third case operation starts with 20 t/h, it drops to minimum during 76 hours, followed by stoppage of 3 hours, while in the last case operation starts with 19 t/h and stoppage time is 2 hours. Operations in every case are repeated until expiration of voyage time, because the plant is stopped during sail through contaminated waters.

Results of this simple analysis are shown on graph 2. For starting and operating conditions during 10 days voyage the highest process capacity is accomplished with the lowest starting capacity of 19 t/h and the operation period of nearly 10 days and the lowest with the highest starting capacity.



Graph 2 The plant's process capacities for different starting and operating conditions

Increase in heat inlet and vacuum in the vessel results with increase in evaporation and plant's capacity. The reduction of those parameters results with decrease in capacity. It seems the first mode of operation is better, but from earlier analysis it's obvious that this isn't so. Furthermore, the increase of vacuum in the vessel will positively affect the evaporation but it will diminish the condensation process taking place in the same vessel. Another setback is creation of brine droplets and their separation from fresh water molecules. It's well known that separator operates poorly when large number of small droplets is created, meaning that the quality of distillate is decreased.

In modern fresh water generator types corrugated plates are used for both evaporators and condensers, but even more, plates are made in one piece. When combined with rubber gaskets evaporator, demister and condenser channels are created, as schematically shown on figure 1. The type of exchanger surfaces wouldn't in any way affect the processes mentioned before. Besides technical layout of the plant and its piping, the figure shows inlet and outlet signals of the management unit.

Main influence on the evaporation process has heating fluid flow through the evaporator and the vacuum in the vessel. Management unit measures the pressure and temperature in the vessel and of the casing respectively, and the distillate's salinity. In accordance with measured values and logic implemented the unit will act on by-pass valve 1 and vacuum breaker valve 3.

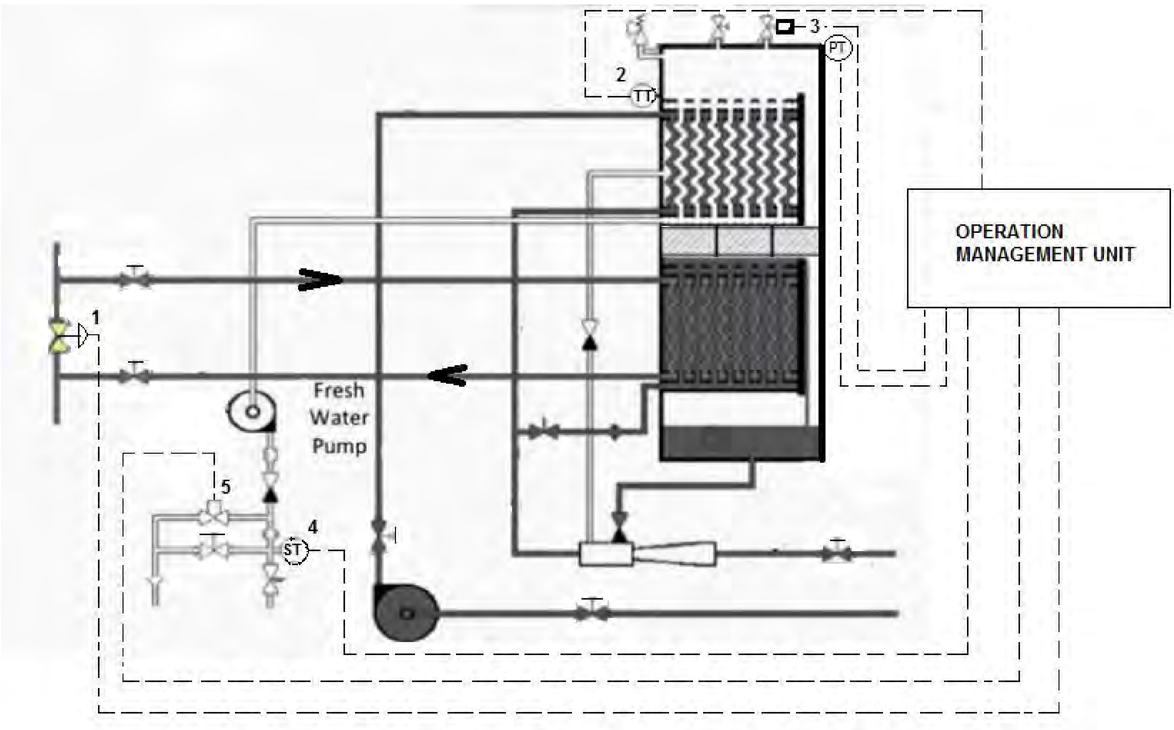


Figure 1 Single stage vacuum fresh water generator and management system

3. THE MANAGEMENT SYSTEM FOR OPTIMAL PROCESS

Let's repeat the reasoning from before. The main effects on the distillation process have: heating fluid flow through the evaporator and cooling fluid flow through the condenser, both of them affected by heat transfer coefficients that are deteriorating with operation hours, the temperature differences between the fluids in those heat exchangers, and the pressure in the vessel.

If maximum cooling fluid flow through the condenser and proper vacuum ejector operation is assumed, the utmost effect would have the temperature difference between the cooling sea water, having the surrounding temperature or being slightly preheated, and the fresh water saturation temperature depending on the pressure in the vessel. There is no objective reason to reduce the cooling water flow, except there is a problem of low flow through the main engine fresh water cooler. The presence of non-condensable gases in the vessel would reduce the condensing effect, and they are removed by the ejector. The temperature difference between the heating fluid and the heated sea water is most important parameter for evaporator performance, but not the only one.

For practical reasons one could assume certain temperature values. The maximum temperature in the process is the temperature of the heating fluid, being the high temperature main engine cooling water, and is determined by the regulating equipment of the system. Usually that is 80°C. The lowest temperature of the process is the sea water inlet temperature, and for 80 up to 90% of the ships it varies from 10 to 20°C.

The empirical Antoine's equation could be used to determine saturation temperature of the liquid according to the pressure. When condensation and evaporation values are compared the second one is slightly higher, because it's sea water. A term boiling point elevation (BPE) is used, and it represents the increase of sea water saturation temperature over fresh water saturation temperature for the same pressure. Since evaporator and condenser temperature differences, i. e. δT_{evap} i δT_{cond}, are together with the respective flows, main heat exchange generators, it is clear the effect of evaporation would be increased, and the intensity of condensation decreased with decrease of the pressure in the vessel. It should be possible to determine for every surrounding temperature the optimal pressure in the vessel, although there will be a small oscillation of pressure in accordance with the pressure management system.

The total energy balance equation for the plant given on fig. 4 is

$$\Delta Q_{heat/HT} + U_{SW} - (\Delta Q_{cond} + U_{brine} + U_{dest} + U_{gas} + Q_{rad}) = m_{cas} c_{cas} \Delta t_{cas} \tag{1}$$

The values in the expression (1) from the left to the right are: $\Delta Q_{heat/HT}$ heat inlet introduced in the process with main engine high temperature cooling water, U_{SW} inlet sea water internal energy, ΔQ_{cond} heat rejected from the process by condenser's cooling sea water, U_{brine} rejected brine internal energy, U_{dest} produced distillate internal energy, U_{gas} internal energy of non-condensable gases removed from vessel, Q_{rad} heat radiation losses to the surrounding (engine room), m_{cas} mass of the plant's casing; c_{cas} specific heat of the casing material; Δt_{cas} the temperature change of the casing itself. A heat introduced in the vessel with the air that enters after vacuum breaker valve opens could be neglected. In comparison with the other values, the last two on the left side of the equation are of lower magnitude, and as such could also be neglected.

During the beginning of the operation heat introduced in the process is higher than the heat removed from it, resulting with increase of casing temperature. The casing temperature would asymptotically approach the upper limit. After stationary condition has been reached, there would be only small disturbances caused by surrounding temperature changes, management system characteristics etc.

The expression's (1) simplification gives an insight of possible simpler and cost efficient management system application. The precision in main parameters regulation would in the same time not be lost and the quality of produced distillate would not deteriorate. The simplification results with:

$$\Delta t_{cas} = K \Delta E \ , \tag{2}$$

where K is a constant including physical values of casing material, and ΔE is a difference of heat inlet and outlet of the process.

4. SIMULATION OF THE DISTILLATION PROCESS

Value of ΔE changes with transient outer and inner conditions:

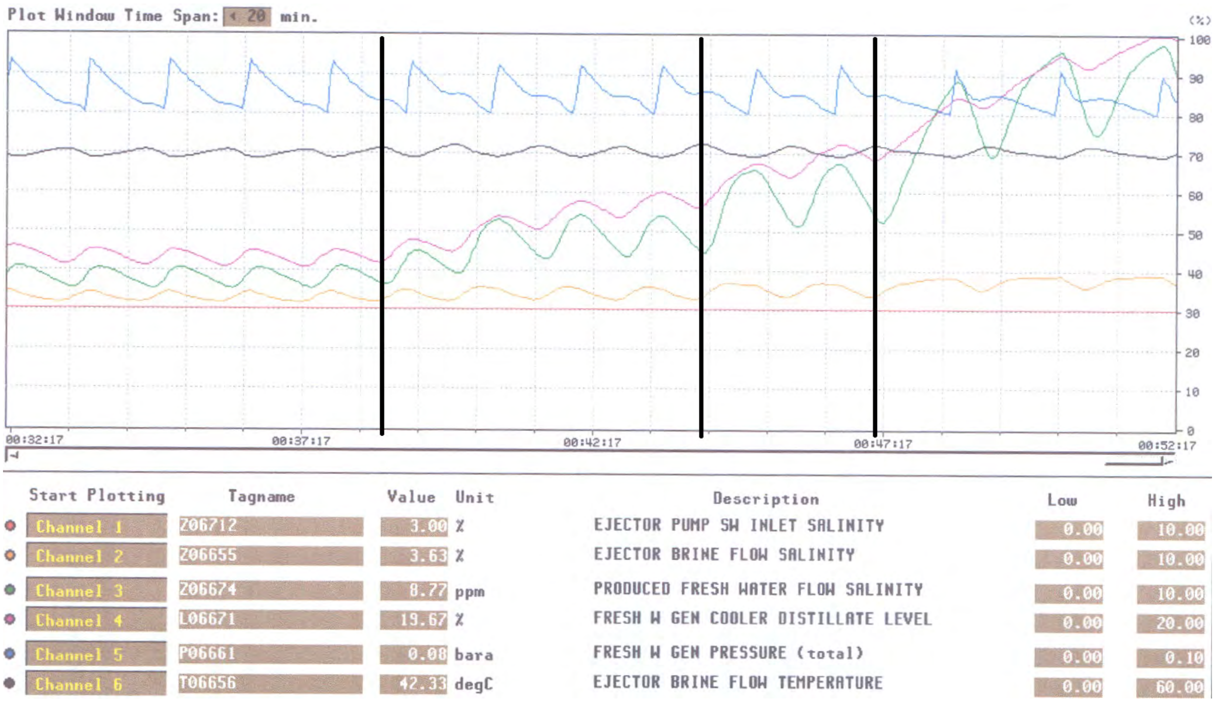
- heating fluid flow is constant in time according to the regulating by-pass valve position, but temperature varies according to the main engine power and the characteristics of the system that regulates the temperature, the heat transfer coefficient changes in time due to the scale formation in particular
- sea water flow should be considered as constant, but its temperature changes with the movement of the ship
- the same stands for condenser's cooling sea water but, moreover heat transfer coefficient also changes in accordance with non-condensable gases or other impurities presence
- heat rejection with brine removed from the vessel depends on first condition and the evaporation intensity
- heat rejection from the process with amount of distillate discharged also depends on the evaporation intensity.

Simulation was carried over on the model in every respect similar to the one shown on fig. 1. The key values have been measured and recorded. Recorded values are given on graph 3.

Six channel plotter was used. The changes are recorded during 20 minutes period (from 32nd till 52nd minute of operation). During that period the position of the by-pass regulating valve was gradually changed. Vertical lines mark the moment when the valve position was in fact changed. Following parameters were recorded: light purple represents inlet sea water salinity (it's constant during the recording time), ocher represents the salinity of the rejected brine, green represents the distillate salinity, purple represents the amount of produced distillate, blue represents the (absolute) pressure in the vessel and black represents the temperature of discharged distillate.

The sinusoidal change of every measured parameter could clearly be seen, except inlet sea water salinity. From the plant's operation explanation presented before, the generator of those sinusoidal changes is vacuum breaker valve, i. e. changes of the pressure in the vessel. The trigger points of the vacuum breaker valve are 91% of vacuum or 0,09 bar of absolute pressure when it closes and 92% of vacuum or 0,08 bar of absolute pressure when it opens. When vacuum breaker valve opens there is a sudden rise of absolute pressure in the vessel and, after it closes, the pressure slowly decreases.

Other dependable parameters follow the same change. Another major influence has change in position of the heating fluid by-pass valve. The vertical lines show the moment of change in the valve position, i. e. the valve was slightly closed, resulting with the increase of heating fluid inlet. The curves show slight increase of brine's salinity and temperature, while at the same time there is a sudden increase of distillate production, and unfortunately its salinity.



Graph 3 The diagram of measured parameter changes [1, 2]

5. CONCLUSION

Of every changeable parameter affecting the plant's operation, especially the distillate production and salinity, the most important are heating fluid flow to the evaporator and the vacuum in the vessel. If proper operation of the vacuum management system is assumed the value of the vacuum would change between two set limits, the pressure would have a sinusoidal change and every dependable parameter would change accordingly.

It is clear the major increase of distillate production can be accomplished with increase of heating fluid flow to the evaporator. Unfortunately, the consequence of such operation is distillate of higher salinity.

The energy balance analysis shows the dependence between energy of the process and temperature of plant's casing. In accordance with the expression a simpler and cost effective management system and advanced information algorithm could be implemented without losing necessary distillate capacity or increasing its salinity.

Other mathematical models should be used to verify that increase of heating fluid causes faster scale formation, increases the operation costs due to crew members working hours an due to material expenses, and in consequence reduces the process capacity of the plant. Also, a model of scale formation dependence on heating fluid and evaporating brine temperatures should be designed in order to determine the optimal process procedures.

REFERENCES

[1] Kralj, P.: Fresh Water Generator Model, Ph. D. Thesis, The Faculty of Maritime Studies University of Rijeka, Rijeka, 2012.

[2] Kralj, P.: Martinović, D., Tudor, M.: Analysis of thermodynamic and technological basics of the marine fresh water generator model, Desal. Water Treat. 95 (2017) pp. 180-185

[3] Kralj, P.: Prijedlog sustava upravljanja vakuumskog generatora slatke vode, Zbornik radova Pomorskog fakulteta, Rijeka, god. 10 (1996), pp. 83-90

[4] Lior, N.: Measurements and Control in Water Desalination, Amsterdam, Elsevier, 1986.

[5] Martinović, D. - Tireli, E. – Kralj, P.: Stanje i razvoj integralnog upravljanja brodom, Zbornik radova Međunarodnog znanstveno-stručnog simpozija o prometnim znanostima, Portorož, 1997., pp. 129-134

[6] Milošević, Š. – Kralj, P.: Simplified Mathematical Model of Vaporization in a Fresh Water Vacuum Distillation Generator, Proceedings from the Symposium "Energy and Environment", Opatija, 1996., pp. 237-244

[7] Milošević Š. – Kralj, P.: Vacuum distillation fresh water generator application on board ship, ELMAR '98, Zadar, 1998., pp. 196-200

[8] Milošević, Š. – Kralj, P.: Vacuum distillation fresh water generator application, Seventh International Expert Meeting - Power engineering, Maribor, Slovenia, 1998., pp. 75-82

[9] Tomas, V., Vlahinić, I., Martinović, D.: Implementation of the Fault Detection and Isolation Method into the Control System, ISEP 99, Ljubljana 1999.

[10] Tomas, V. – Kralj, P. – Tudor, M.: A modern freshwater generator processes control system, ELMAR '98, Zadar, 1998., pp. 226-229

[11] Tudor, M.: O pouzdanosti brodskih sustava, Pomorstvo, Vol. 17, 2003, pp. 11-20

[12] Tudor, M.: Analiza pojave kvarova kod brodskih sustava, Pomorstvo, Vol. 15, 2001, pp. 97-103

[13] Tudor, M., Bukša, A., Kralj, P.: Održavanje brodskih sustava, Pomorstvo, Vol. 18, 2004, pp. 29-42

[14] Tudor, M. - Kralj, P.: Utjecaj rizika kvara na računalni odabir pristupa održavanju brodskih sustava, Pomorstvo, Rijeka, Godina 14 (2000), pp. 43-52

[15] VDI Heat Atlas, 2. English ed., Düsseldorf, VDI Verlag, 1991.

List of symbols

c [$Jkg^{-1}K^{-1}$] specific heat capacity
m [kg]mass
ΔQ [J] heat difference
Q [J] heat
Δt [°C] temperature difference.
U [J] internal energy

Indexes

brine – water and salt concentrated solution
cas – casing
cond – heat input into the condenser with the cooling seawater
dist – distillate
gas – exhaust gases
heat/HT – heat input with the main propulsion engine high temperature cooling water
rad - heat lost by radiation into the engine room
SW – sea water

RESEARCH OF THE OPERATION PROCESSES OF THE SYSTEM "MARINE PASSENGER TERMINAL- FERRY LINE" BASED ON SIMULATION

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UDK 656.615:52-17

Summary

According to statistics, the marine passenger transportation sectors (both cruise lines and ferry lines) show a significant increase of passenger traffic and the intensity of ship routes. But new features of the conditions for passenger traffic growth require the development of new methodological transport models for cruise and ferry networks and new practical forecasting methods. Changes are observed in the fleet composition, mostly in the direction of increased. New approach for forecasting has to be based on the interaction of such systems as «sea passenger port - cruise and ferry lines». The object of the research is the Adriatic and Baltic Sea regions and the existing route networks of cruise and ferry lines. Exploring this system, it was justified the usage of new mathematical apparatus based on correspondence matrices and agent based simulation for estimating the workload on transport infrastructure around the passenger port, and for the existing ferry or cruise route network. This new results could improve the quality of decision making process in forecasting the route network based on the research of passenger traffic between systems «city - sea terminal - cruise line or ferry line». To reflect the dynamics of changes in such a system, it is proposed to use new circos plot intensity diagrams. The article presents new main trends for sea ferry transportation, justifies simulation based on discretization and practical application of Kotelnikov's theorem, discusses the practical importance of using circos plot intensity diagrams to research the operation of the «marine terminal - cruise line or ferry line» systems based on real data. Based on the simulation results, a new corrective action system is proposed to enhance the management of marine terminals.

Keywords: transport processes; mathematical modeling; simulation; ferry network; cruise network; transport hub, marine passenger terminal, passenger traffic, ferry line, circos diagram, intensity

1. INTRODUCTION

Marine passenger ports and terminals are integral part of the transport complex of any region. They play a significant role in the processes of passenger service and transportation and are a link in the system as «ferry company - terminal - city system». These processes of formation have strong influence on historically established terminals near the historical centers of famous cities themselves. But today the segment of passenger shipping has increased significantly. Under the influence of the external environment, two trends emerged in the development of sea passenger terminals:

1. trend of building large cruise liners;
2. construction of new separate terminals and expansion of ports to attract new passenger traffic;
3. changes in the route networks of ferry carrier companies, entering new markets, including new ports and terminals located in the northern seas on a cruise.

So, this transport marine industry is in the process of renovation, the construction of new marine terminals and the modernization of existing terminals. To confirm these trends we can look at the forecast data on fig.1 shows (presents) the potential of the ferry and cruise transportation market until 2022 year [1,2]. Innovation refers to the construction of new terminals and changes in route networks.

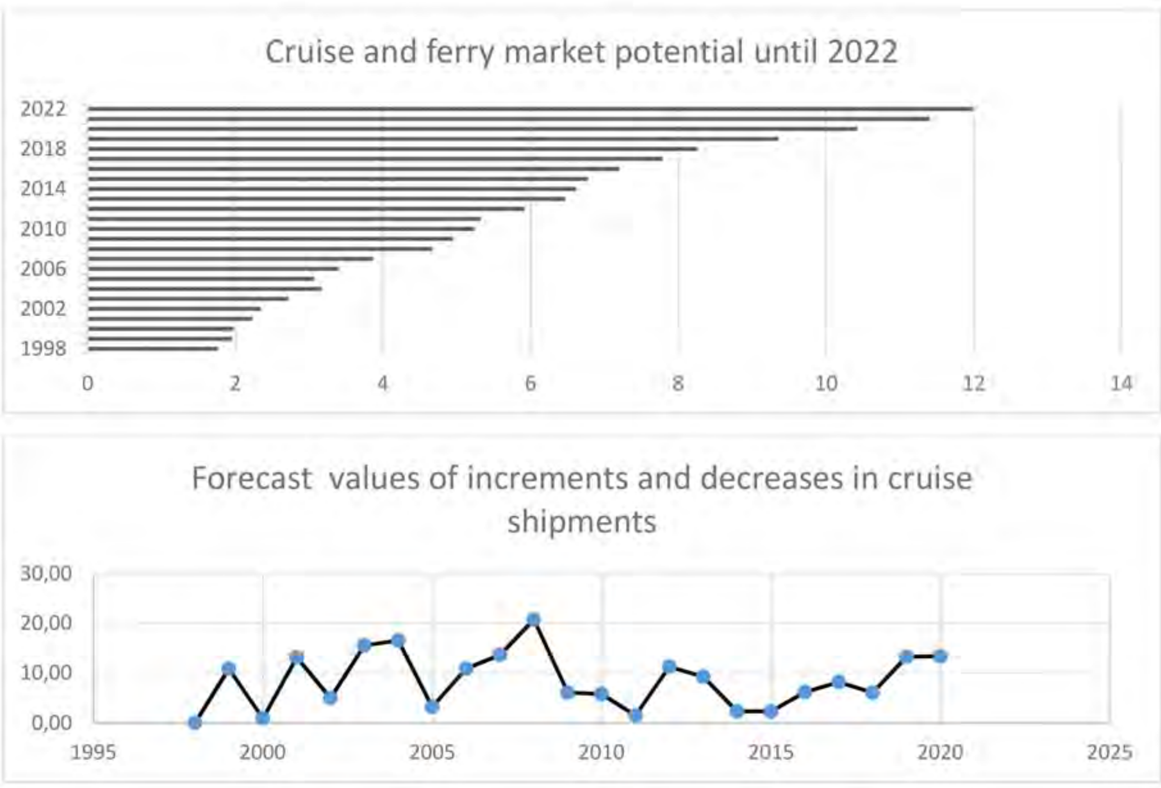

Figure 1 Cruise market potential, mln. people (according to CINN 2018 EUROPE. European Cruise Lines)

Today, the main objects of research can be:

1. technological and organizational processes of a separate sea passenger terminal;
2. technological and organizational processes of a cruise or ferry company;
3. systems interaction of systems «marine ferry company - passenger port - city megalopolis».

If the research of terminal processes leads to the solution of some problem of effective planning and organization, then the research of the interaction of systems requires the development of new dynamic models and methods. Especially the task is actual in forecasting the development of the seaport and the terminal to preserve and increase passenger traffic and the intensity of cruise and ferry ships [3,4].

Plans for the development of the various components of the passenger port system depend to a large extent on the activity levels which are forecast for the future. Since the purpose of an passenger port is to process passengers and ferry ships in an efficient and safe manner, passenger port performance is judged on the basis of how well the demand placed upon the facilities within the system is handled.

Over the years, certain techniques have evolved that enable passenger port planners and designers to forecast future demand. The principal items for which estimates are usually needed include the following:

- the volume and peaking characteristics of passengers, vessels and cargo;
- the number and types of vessels needed to serve the above traffic;
- the performance and operating characteristics of passenger port access systems.

In view of the fact that it is very difficult to predict the influence of the external environment on long-term traffic prediction of passenger terminals and the global market, it is proposed to use simulation modeling in the form of information transport models [5,6]. The most suitable program for creating transport models is Anylogic. These technologies must solve forecasting problems based on real data and task of operational processes [7, 8]. Using simulation and techniques, estimates of these parameters and a determination of the peak period for volumes of passengers can be made. From these estimates, concepts for the layout and sizing of sea terminal buildings, types of cruise and ferry ships, ships and ground access facilities may be examined. There are different approaches to simulation methods in logistics. This article provides an intelligent method based on simulation using real data.

2. MODELS AND METHODS FOR SIMULATION SYSTEM «MARINE PASSENGER TERMINAL- FERRY LINE» BASED ON DISCRETIZATION

Simulation modelling is an excellent tool for analyzing and optimizing dynamic processes. Specifically, when mathematical optimization of complex systems becomes infeasible, and when conducting experiments within real systems is too expensive, time consuming, or dangerous, simulation becomes a powerful tool. The aim of simulation is to support objective decision making by means of dynamic analysis, to enable managers to safely plan their operations. Simulation models use mathematical or logical constructs and calculate the final solution. But for each process, it is necessary to use models adequately describing the process. For research marine passenger processes in transport systems, the most widely used tools are as follows: Linear programming; Network Optimization; Game Theory; Dynamic Petri networks; Decision Analysis; Markov Chains; Queuing Theory; Queuing system [6]. In overview of the use of a large number of terminal schedules, it is necessary to use modeling based on the theory of discrete processes and systems. With this approach, it is necessary to introduce a new term for the state of the marine system. The state of the system refers to such characteristics as the number of routes of ferry lines, the number of sea passenger terminals, the value of passenger traffic and the intensity of ferry ships. Based on the state of the system, it is possible both to solve operational tasks and to evaluate forecasts in the development of the system and simulation. For detail, each state is characterized by a different capacity of the terminal, different passenger traffic and different workload of sea berths and services. A general view of the interaction of terminals is presented in fig. 2.

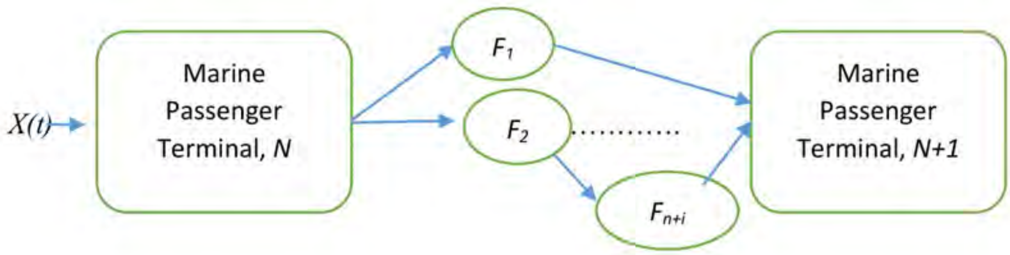

Figure 2 General scheme of interaction «marine passenger terminal- ferry line»

In figure 2 $X(t)$ - Input intensity of cruise and ferry ships;$F_1,\ldots,F_{n+1}$- various routes between terminals; $N,N+1$ - marine passenger terminal.

In the papers of some authors [8, 9], to calculate the states of a system, it is necessary to determine possible state transitions. Since each state is characterized by a certain set of infrastructure variables, for their transitions it is necessary to calculate their probabilities. Let to ensure the smooth operation of the terminal involved no more than *n* berths. At the entrance of the system comes the schedule of ship calls. Transitions of the system are represented in the form of a directed graph [10, p.189] and then the system is described by the Kolmogorov equations in the following form

$$\begin{aligned} & dp_0(t)/dt = \mu p_1(t) - \lambda(t) p_0(t), \\ & \ldots \\ & \mathrm{d}p_i(t)/dt = \lambda(t) p_{i-1}(t) + (i+1)\mu p_{i+1}(t) - (\lambda(t) + i\mu) p_i(t) \qquad (i = 1, 2, \ldots, \mathrm{n}-1), \\ & \ldots \\ & \mathrm{d}p_n(t)/dt = \lambda(t) p_{n-1}(t) - n\mu p_n(t) \end{aligned} \tag{1}$$

and boundary condition $\sum_{i=1}^{n} p_i(0) = 1$,

where *λ(t),μ (t)* is a function of the intensity of transitions from one state to another; *i* - the index corresponding to a particular state; $p_i(t)$ is the state probability function.

This set of equations accurately describes the transitions between different states for sea passenger terminals. Finding a solution to system (1) in general and for an arbitrary function presents considerable difficulties. The use of the Kotelnikov's theorem is proposed. This theorem allows finding the necessary system states. Any graph is represented by a set of its discrete values. The function of the marine system *F(t),* consisting of a certain discrete set of states, can be continuously determined with any accuracy using the values of the states following each other through $\Delta t = \frac{1}{F_n}$. The time moments of the system states are defined as $t_k = k\Delta t$, subject to distance from each other for a time interval $\Delta t = \frac{1}{2f}$. Recovery of any state of the system is determined by the formula

$$x(t) = \sum_{k=0}^{K} x_k \frac{\sin \omega_в (t - k\Delta t)}{\omega_в (t - k\Delta t)}, \tag{2}$$

where $\omega = 2\pi f$.

The process of accurately finding the state of the system, according to the available discrete values, is represented in the following form of fig. 3.

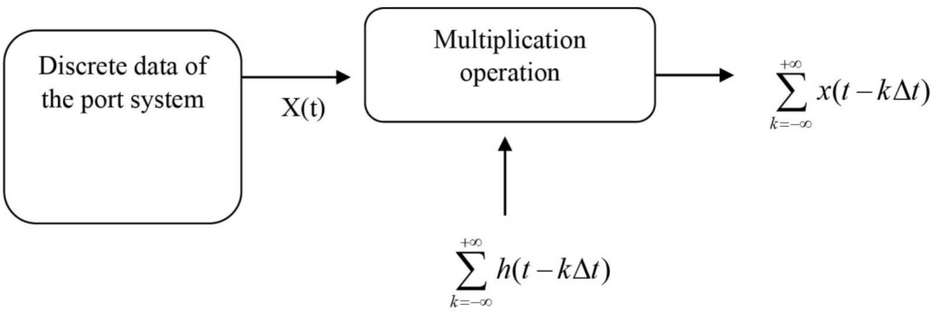

Figure 3 The process of discretization of system states

In figure 3 one input receives the initial continuous process *x (t)* of the port system, the second input receives a system of single discrete values, following each other with a period. Based on the interpolation of the system states, the decision maker must form a system for making corrective decisions.

Consider restoring the state of the marine system based on Passenger Port of Saint Petersburg "Marine Façade" [16]. For the initial data, we take the total annual passenger traffic. So, we will take a discrete interval from 2014 to 2017 year and estimate the expected level of 2016. According to statistical information, passenger traffic amounted to 456 495 passengers. In the general graph at this stage, there is a decrease compared with previous years. The equation for the calculation is as follows

$$X_{2016} = F_{2014}\frac{\sin(\omega t_{2016})}{\omega t_{2016}} + F_{2015}\frac{\sin(\omega t_{2016}-\pi)}{\omega t_{2016}-\pi} + F_{2017}\frac{\sin(\omega t_{2016}-2\pi)}{\omega t_{2016}-2\pi}, \quad (3)$$

where t_{2016} - discrete time for which we need to calculate the state of marine system; F_{2014},F_{2015}, F_{2017} values for passenger traffic.

Simulation based on the Kotelnikov theorem and recovery of system values by passenger traffic (figure 4).

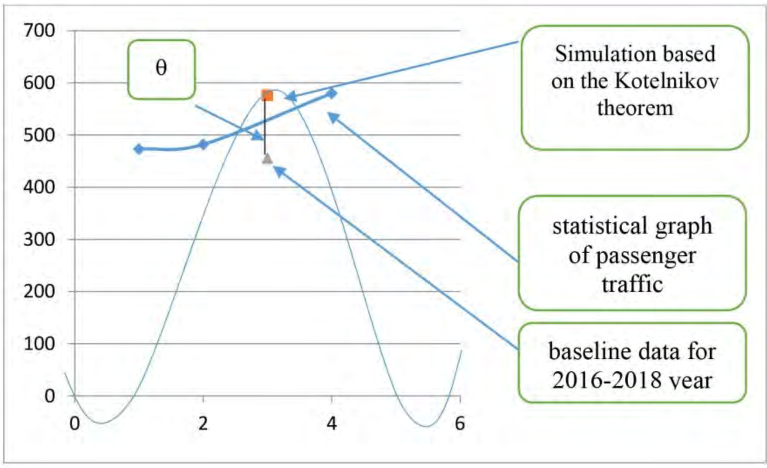

Figure 4 Realization of interpolation and modeling of system states using discrete values

Based on the result (fig.4), it turns out that, based on the available data, the passenger traffic for 2016 year should have been 561 378 passengers. The discrepancy in the values is θ= 104883 passengers. This conclusion can be applied to any set of discrete states of the system and allows you to find any state. The given example allows us to estimate the losses for the system. However, the presented model and methodology can be scalable in accordance with time intervals. In this case, these mathematical models justify the discrete nature of the processes for sea passenger terminals. Input data for the model are passenger traffic and cruise ship and ferry arrival rates. The obtained and reconstructed values must be used for modeling and subsequent decision-making. Based on this model, it is possible to evaluate the operation of the terminal and decide on the reasons for the failure to achieve the planned passenger traffic indicators.

3. SIMULATION OF SYSTEM «MARINE PASSENGER TERMINAL- FERRY LINE» BASED ON CIRCOS DIAGRAM

In the passenger port sector, infrastructure development and the acquisition of handling equipment are justified mainly by the potential traffic. Meeting this demand is the purpose of any investment in a commercial port. Thus, we can't easily expect the development of any marine passenger port without first proving a minimum of traffic (passengers and cruise or ferry ships, their intensuty and quality) to be handled.

Thus, the quantification of potential traffic is the first step to build a rational process of decision making. But, what way is more actual now ? At this moment most effectibe way is simulation methodoligy based on real dates and geoinfirmation systems of passengers terminals. To simulate the workload of the sea passenger terminal, it is necessary to estimate the traffic intensity of cruise ships and ferry ships. Different passenger capacity of ships determines different load for the terminal. On the other hand, each terminal is interested in increasing the route network. Let's look on regions of the Adriatic and Baltic Seas.

Ferries in Croatia connect the Croatian coast with all inhabited islands. Ferries to Croatia connect Croatian ports with Italy and nearest countries. The major Croatian passenger (cruise and ferry) ports are Split, Zadar, Rijeka, Šibenik and Dubrovnik. Dubrovnik is an Adriatic Sea cruise port and city in Croatia, and one of Europe's historically most prominent and popular vacation travel destinations [12]. Ferries in Baltic Sea, passenger shipping on the serve as the backbone elements of the Baltic transnational macro-region [13, 14].

Table 1 Trends of traffic in some ports in Adriatic coast region

	Parameters	Dubrovnik	Zadar	Split	Šibenik
2014	Domestic (pax)	405.121	2.080.811		39.992
	Cruise (pax)	806412	53.791	184.062	12.693
	Cruise calls	460	77	233	93
2015	Domestic pax)	452.904	2.156.480		259.106
	Cruise (pax)	768.434	70.366	271.445	17.562
	Cruise calls	475	92	261	92
2016	Domestic (pax)	479.634	2.238.312		276.234
	Cruise (pax)	799.916	136.462	278.259	12.276
	Cruise calls	529	114	286	105
2017	Domestic pax)	594.609	2.348.950		
	Cruise (pax)	704.812	137.667		
	Cruise calls	443	110		
2018	Domestic (pax)	606.094	2,351,095		
	Cruise (pax)	732.431	166,52		
	Cruise calls	414	120		

Table 1 presents data from open sources [12]. On the basis of the schedule of ship visits, it is possible to analyze the intensity of work for six months. According to the statistical data from *EUROSTAT* [15], given in table 2, there is a significant increase in passengers transported to/from main ports of Croatia in quarterly data. Cruise calls for port Dubrovnik behind six month 2019 presents on fig.5.

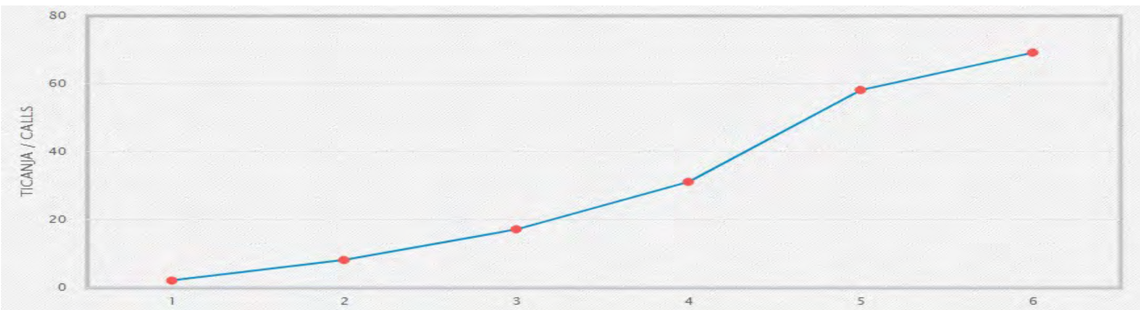

Figure 5 Cruise calls for port Dubrovnik behind six month 2019

Table 2 Passengers transported to/from main ports - Croatia - quarterly data (in thousand passengers)

Ports	2016/ Q3	2016/ Q4	2017/ Q1	2017/ Q2	2017/ Q3	2017/ Q4	2018/ Q1	2018/ Q2	2018/ Q3	2018/ Q4
Dubrovnik	691	103	38	357	777	117	30	374	827	130
Poreč	150	10	0	56	160	11	0	58	157	14
Preko	706	328	294	451	724	324	283	451	737	323
Pula	242	55	20	168	231	58	21	173	248	62
Rovinj	29	3	:	10	38	1	:	17	59	4
Šibenik	286	60	37	139	286	60	34	154	276	62
Split	2 170	594	441	1 117	2 190	591	445	1 212	2 369	625
Zadar	918	378	333	542	960	372	322	551	980	375

By the Baltic macro region, we will mean an integrated international region that includes the entire set of economic activities and represents a network model of cooperation with the presence of both horizontal and vertical links. With the efforts of 52 seaports out of 184, providing services for both cruise and ferry transportation of passengers. The Baltic region is unique due to the proximity of various countries and the opportunity to get acquainted with a large cultural layer during one cruise. According to the source [15, 16, 17], only from 10 to 16 June 2019, the passenger port was visited by nine cruise ships, on which 25660 passengers arrived. In total, the ships stayed at the port berths for 17 ship-days, the total number of passenger operations performed was 100,985. Additionally, it is necessary to note the fact that the number of days of maximum load of the passenger terminal significantly increases. When the terminal was at the same time from 5 to 7 ships, the number of loading days was 46 days, which is 31.4% more than last year's navigation. For example, on June 30, 2018, a new record for the number of passengers received per day was set in the passenger port of St. Petersburg. 18198 tourists descended from the six cruise ships to the coast. That is why, on the basis of a study of the carrying capacity of the passenger port, the possibility of more efficient scheduling of services and divisions opens up. Capacity means the maximum number of passengers and cruise ships that a passenger terminal can handle in accordance with its production capabilities for a certain period. The capacity of the passenger terminal as a whole depends on the capacity of its individual elements and services. When using simulation modeling of the terminal, it is possible to improve the quality of planning, since this is the way to confirm the correctness of organizational decisions. In [8], the developed tools are presented, which allow to plan terminal operation based on modeling in the AnyLogic environment.

According to the statistics of Passenger Port St. Petersburg "Sea Facade" , there is a significant increase in passenger traffic and the intensity of cruise ships, compared to 2016-2017. Of course, in addition to stimulating the attraction of foreign tourists arriving by cruise and ferry ships, there is a visa-free regime for 72 hours in Russia.

For the formation of conditions for effective planning of the work of the marine passenger terminal, we choose the intensity of cruise lines as a basis. Based on the analysis of ship call schedules for 2018, passenger capacity was determined and vessel call schedules were built (Fig. 6). Based on this analytics, wecan explore the workload of the terminal. Thanks to the replay of ships for navigation in 2019, you can plan the operation of the terminal and, if possible, optimize it. Consider a fragment of the schedule of visits of cruise ships to the port (table 3).

Table 3 The some fragment of list of cruise ships calling at the port in navigation in 2018 in the Passenger Port of Saint-Petersburg "Marine Façade"

Cruise ship	Berths in use at the port	Country	Passenger capacity
Viking Sea	1,2,3,4	Norway	930
MSC Preziosa	1,5,7	Panama	4378
Regal Princess	1,5,7	Bermuda	4272
AIDAcara	2,3,5,6	Italy	1186
Rotterdam	1,5	Netherlands	2220
Brilliance of the Seas	1,5,7	Bahamas	2500
AIDAmar	1,3,5,6,7	Italy	2500
Zenith	1,3,5,6	Malta	1442
AIDAdiva	1,2,3,5,6,7	Italy	2500
Zuiderdam	5,6,7	Netherlands	1916
Celebrity Silhouette	1,5,7	Malta	2850
MSC Orchestra	1,6,7	Panama	3060
Costa Magica	1,5,6,7	Italy	3470
Norwegian Breakaway	1,7	Bahamas	3963
AIDAbella	1,2,5,6,7	Italy	2500

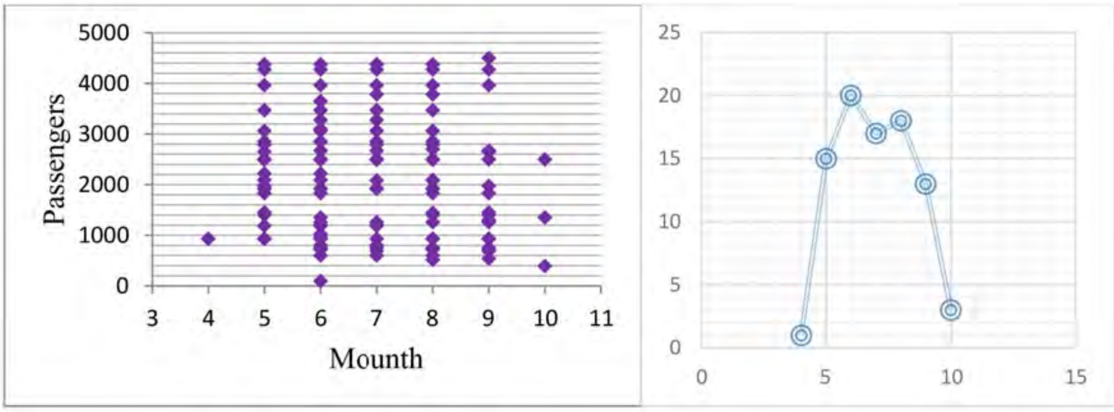

Figure 6 Ship call schedules for 2018 and passenger capacity in Passenger Port of Saint-Petersburg "Marine Façade"

To simulate the operation of the system «marine passenger terminal- ferry line», the article [18, 19] suggests using CIRCOS diagram. With this approach, the communication diagram provides a structured approach to the analysis of complex interactions between passenger terminals, which is its strength. At the same time, the diagram on its elements allows placing additional analytical information, such as work intensity, workload and others. Ferry traffic intensities and simulation results based on the Circos diagram are presented in Figure 7.

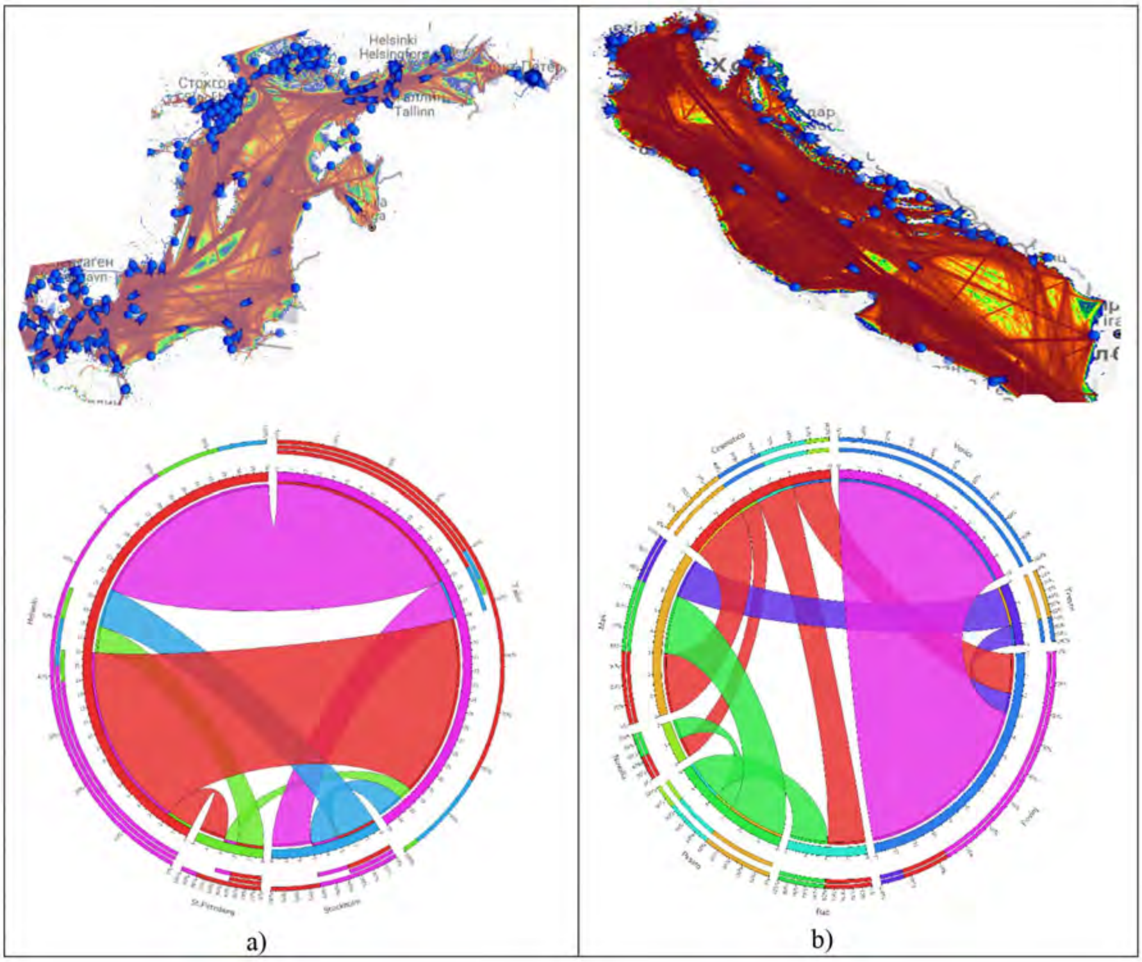

Figure 7 The results of the simulation system «marine passenger terminal- ferry line» work for the terminals of the Baltic (a) and Adriatic (b) seas

The information graphs (figure 7) also contains analytical information on the mutual influence of passenger ports, presented in the form of corresponding circular scales. This analytical material makes it possible to predict decision making already at the macro level of planning, since it also provides information on the mutual influence of terminals. As a result, the use of circular communication diagrams makes it possible at the macro level to investigate the operation of the «maritime passenger terminal - ferry line» system.

4. DECISION MAKING PLAN FOR CORRECTIVE ACTION TO THE MARINE PASSENGER TERMINAL

Based on the simulation results and the calculations made, the decision maker should form a system of making corrective decisions to minimize errors in the operation of the seaport. The general scheme of the formation of corrective actions (Figure 8).

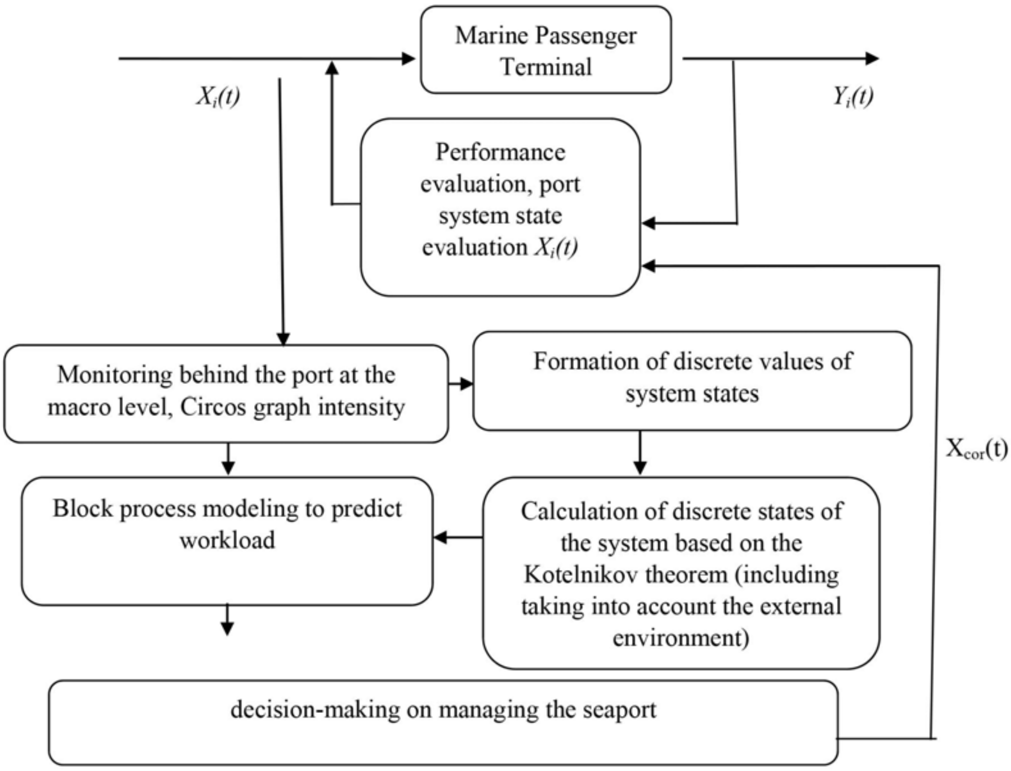

Figure 8 Scheme of formation of corrective action to the marine passenger terminal

Based on figure 6 and the proposed methodology for simulation of the operation of the system, taking into account the corrective action *Xcor (t)* of the system states is added to the control decision loop. The calculations are based on simulation, the use of a circos graph, the interpolation of system states on the basis of the Kotelnikov theorem. At the same time, this technique should be used in parallel with the unit for simulation operational activities. Based on the simulation, the predicted load of the infrastructure elements is determined and then the states are calculated, while using the proposed technique it is possible to directly calculate the required state of the port system.

From a system point of view, the implementation of this decision-making system requires organizational changes. It is necessary to create a separate analytical department that will collect data from all processes of the passenger terminal. The implementation of the model requires the creation of a specialized information transport model, for example in the AnyLogic environment, connected to the information systems of individual terminal processes. It is an imitation transport model that will allow the implementation of the processes of the sea terminal at all levels of management. From the study of one process, for example, inspection or check-in of passengers, to the study of the work of the whole chain of processes Using this approach will allow to visualize processes, collect analytics and improve the quality of forecasting the development of the marine passenger terminal.

5. CONCLUSION

When studying the development tasks of marine passenger terminals, it is necessary to use flexible tools and techniques. As it is well known, under the influence of the external environment, constant changes occur both in the route ferry networks and cruise lines, and in the organizational processes of each passenger terminals. The main information tool for making decisions on planning, optimization, forecasting is simulation modeling. However, effective using apparatus of simulation should be based on mathematical models and methods that accurately describe the processes. The object of the study was selected regions of the Baltic and Adriatic seas and existing route networks of ferry lines.

The article proposes to use the new process discretization models (Kotelnikov's theorem) to research the «marine passenger terminal- ferry line» system to determine the terminal capacity values and evaluate the operation of the terminal itself. The model can be used for any time interval of research. To confirm the correctness of the model analysis was conducted for Passenger Port of Saint Petersburg "Marine Façade". It is proposed to take into account the impact of the environment through a probabilistic function and take into account both positive and negative effects of the external environment. Method can be used both in parallel with the operational modeling of the port system, and separately, for given discrete values. It can be used both at the macro level of the system and used to analyze individual nodes at the micro level. The proposed methodology is expected to be useful at the stage of operational management of the terminal and the feasibility study.

Then, it is proposed to use Circos diagrams to assess the impact of the terminal system of each other and research changes in the ferry transport market. The model can be scaled. The proposed path of study can be used for any number of passenger terminals and the model can be scaled. When a system is formed from data diagrams built over a selected time interval, it is possible to justify system changes, which cannot be determined by working with separate tables and analytics models.

On the basis of such model a new scheme of corrective action for the marine passenger terminal is proposed. This technique allows for a qualitatively new level to investigate the system «marine passenger terminal-ferry line» and significantly improves the accuracy of forecasting and planning tasks.

REFERENCES

1. *CINN 2018 EUROPE. European Cruise Lines.* Available at: https://www.cruiseindustrynews.com/pdf

2. Economic Impact of Cruise Activity: The Port of Barcelona. – IREA: 2016, - 30 p.

3. Unctad monographs on port management. The economic impact of cruise ports: The case of Miami. - New York and Geneva, 2001. – 33 p.

4. Handbook of Terminal Planning /edited by J. W. Böse. — Springer Science+Business Media, LLC, 2011. — 456 p. DOI: 10.1007/978-1-4419-8408-1.

5. *AnyLogic*. Available at: https://anylogic.com (accessed 01.07.2019).

6. Maiorov, N., Fetisov, V. (2012). Prakticheskie zadachi modelirovaniia transportnykh sistem [Practical Problems of Modeling of Transport Systems]. Saint Petersburg: SUAI Publ., 185 pp. (In Russian)

7. Maiorov, N. N., Fetisov, V. A. Improvement of the quality of the sea passenger terminal based on methods of forecasting**.** Naše more (Our Sea). 2018. Vol 65. No 3. pp. 135-140

8. Krile, S., Maiorov, N., Fetisov, V. *Forecasting the operational activities of the sea passenger terminal using intelligent technologies*, Transport Problems, 2018 Vol 13 (Issue 1), pp. 27-36. DOI: 10.21307/tp.2018.13.1.3

9. Ivanov, B. A., Nedviga, A. V. (2007). Elementy teorii diskretnykh sistem avtomaticheskogo upravleniya. Ukhta: UGTU, 112 p. (In Russian)

10. Vencel' E. S. *Teoriya sluchajnyh processov ee inzhenernye prilozheniya.* M.: Nauka, 1991.

11. Naumova N., Danovich L. A model of flows distribution in the network. *Life Science Journal*. 2014. No 11 (6). P. 591–597.

12. *Passengers transported to/from main ports - Croatia - quarterly data*. Available at: http://appsso.eurostat.ec.europa.eu /nui/show.do?dataset=mar_pa_qm_hr&lang=en (accessed 1 July 2019)

13. *Cruise Europe. Port Handbook (2018).* http://www.cruiseeurope.com/ (accessed: 15. 4. 2018)

14. Baltic Port list 2006. Annual cargo statistic of ports in the Baltic Sea region/ A publication from the center for maritime studies university of Turku: — Turku, 2012. 120 p.

15. Passengers transported to/from main ports - Croatia - quarterly data. Available at: http://appsso.eurostat.ec. europa.eu/nui/show.do?dataset=mar_pa_qm_hr&lang=en (accessed 11 February 2019)

16. *HELCOM.fi.* Available at: http://maps.helcom.fi/website/AISexplorer/ (accessed 01.07.2019).

17. *Passenger Port of Saint-Petersburg "Marine Façade".* Available at: https://www.portspb.ru/

18. Krile, S., Maiorov, N., *Work Analysis of Maritime Passenger Terminals for Particular Region Based on Circos Plot***.** Naše more (Our Sea), 2019, Vol 66, No 2, pp. 57-61.DOI: 10.17818/NM/2019/2.2

19. *Circos.* Available at: https://sourceforge.net/projects/jcircos/ (accessed 11.07.2019).

APPLICATION OF THE MICROSIMULATION TRAFFIC MODEL IN ASSESSING CONGESTION OF THE CONTAINER TERMINAL “BRAJDICA” ACCESS ROAD NETWORK

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Summary

The constant increase in the turnover of the container terminal "Brajdica" is correlated with the load of the access road network, i.e. with the increasing degree of congestion, assuming that the shares of transport modes involved in the delivery / dispatch of containers are not changed. The aim of this paper is to use the micro-simulation traffic model and the PTV Vissim computer program to carry out simulations of several scenarios to assess whether the throughput rate of the access road traffic network is sufficient with respect to the existing as well as to possible future traffic loads that are assumed to be constantly increasing in compliance with the achieved annual rate of container terminal turnout growth.

Keywords: state road D-404, container terminal „Brajdica“, microsimulation traffic model, traffic load

1. INTRODUCTION

Due to the increasing container turnover and traffic load of the terminal, increasing requirements are added to the existing road traffic network, i.e. on road junctions, requiring their designed throughput capacity to provide an unobstructed and safe traffic flow. Today, analyses of the throughput rate of certain sections of the road traffic network use the simulation modelling method [1] [2]. The application of this method results in the creation of a simulation model enabling many input variables to carry out "what if“ analyses to provide the possibility for making concrete conclusions about the defined issue. [2] The issue of a research can be defined as follows: load increase and consequently the throughput rate of the road traffic network that allows connection of the "Brajdica" container terminal with the hinterland or its gravity area is becoming an increasingly pronounced issue in terms of traffic flows. An adequately developed road network that connects the terminal with the hinterland increases the rate of its domination within the gravity area [3]. Thus, the "Brajdica" container terminal connection with the hinterland is enabled by state road D-404, the A7 motorway (Rupa-Križišće) and the A6 motorway (Rijeka-Zagreb) [3]. The design and construction of each of these roads must allow for a smooth traffic flow with respect to existing as well as future traffic loads. The most important part of the mentioned road network is the access road to the "Brajdica" container terminal, enabling direct connection of the terminal with the state road D-404. In compliance with the problem and the topic of the research, the hypothesis of this paper is: In order to determine how the "Brajdica" container terminal increasing turnover affects the road network load and its throughput capacity, and to determine the point of the "Brajdica" container terminal turnover growth at which the terminal will be affected by congestion of the selected segment of the road network, a microsimulation traffic model can be applied. The purpose and aim of the study are to use the collected and assumed data on the traffic load of the road network caused by the growth of container turnover at the terminal "Brajdica" to determine the presence of existing and also future bottlenecks in the observed segments of the road network based on the simulation of the microsimulation traffic model and thus to determine the container turnover rate at which bottlenecks will appear and prevent smooth traffic flows. The microsimulation traffic model was developed applying a modelling method using the PTV Vissim microsimulation tool, and the obtained results were analyzed using a program package R intended for the implementation of descriptive statistical analysis and graphic presentation of defined variables.

2. CONNECTION BETWEEN SIMULATION MODELLING AND SEA PORTS

The prerequisite for a simulation model to be developed is the existence of the observation system. In simulation modelling the system is a separate part of the real world being explored [2] [4]. Each observed system consists of several components (elements) connected to a unique interactive set [2] [5]. The state of each system at a given moment is the result of the current state of all system components [2]. The basic role of the simulation model is based on the formulation of new idPCEs for setting and proving hypotheses and designing and researching features of new solutions that often cannot be examined otherwise [6]. The application of the model enables a description of complex phenomena of the real world and also enables their better understanding.

By using simulation modelling, a detailed insight is obtained into the operation of the system represented by the simulation model. Some observable systems can be so complex that it is almost impossible to understand their operation and their interactions exclusively by observing them without presenting the system through a model [4]. In most cases, stopping or hindering the operation of the observed component of the actual system to detect its deficiencies is unacceptable, and even if so, there is a high probability of obtaining unreliable results. It can be easy to determine shortcomings of the observed system and to have an insight into modifications in its operation by way of designing and applying a simulation model.

2.1. Basic features of simulations in the traffic sector

Performing simulation in the traffic sector has long been the most appropriate and convenient way to predict future as well as to track the operation of current traffic situations. Simulations within the traffic sector are most widely applied in the sphere of the road traffic and thus have a significant role in the traffic planning and design process [7]. Thus, the decision on the construction or reconstruction of the existing road network is primarily based on the implementation of simulation models or the results obtained using the so far very sophisticated and "user friendly" simulation tools. Due to their unpredictability or stochastic nature traffic situations are subject to significant changes that cannot be easily noticed by applying classic mathematical models. [5] [8] The application of models that cannot cover the number of changes that occur within a traffic situation will cause the impossibility of accurate projection or predicting future situations. Every situation in the traffic sector is specific to the others. Traffic situations change in dependence on the time, place or even behaviour of traffic participants, as can be best detected and predicted using simulation tools [8]. The use of simulation in the traffic sector is based on the simulation of discrete events, simulation of such states that change discontinuously in time or only at certain times [2]. Traffic simulation models use algorithms to define traffic flows of vehicles in the observed time and space, enabling their interaction [2] [4]. Vehicle interaction within the traffic network is accomplished by determining the borderline values of defined parameters such as speed, acceleration, deceleration, etc., that the trajectories of other vehicles in the distant part of the traffic network depend on. Dynamic display of traffic flow within a simulation tool allows for a more thorough assessment of developments in the selected segment of the traffic network. Traffic simulation models are stochastic by nature, meaning that they use random variables or probability distributions to describe the traffic flow [9]. Randomly selected variables based on probability distributions allow the input data to not always display the same solution. For this reason simulation is repeated several times in order for the final results to be obtained from the mean values of the observed output parameters for each of the simulations carried out [2] [4] [5]. The procedure of successive repetition of simulations results in an increase in the statistical reliability of the observed output parameters.

2.2. Container terminal "Brajdica" – the basis for the simulation traffic model

Nowadays, when the interaction of the system components has become so comprehensive that it is impossible to confirm the delimitation of their actions with certainty, the application of simulation tools has become an indispensable factor of many researches. The simulation models that are the basis of the application of simulation tools are largely adapted to the different requirements of the traffic sector and are therefore further developed and adapted for this purpose. Consequently, in the traffic sector simulation tools are used primarily to present the existing traffic situation and, if need be, to be optimized and to provide conditions that will meet any existing as well as future traffic needs [10] [11]. Since simulation models have become a highly accepted and innovative way to carry out different analyses, both sea ports and individual terminals have become more and more interesting objects for simulation modelling and simulation research.

Owing to the constant increase of container turnover in the port of Rijeka, located on the north Adriatic traffic route, the "Brajdica" container terminal of Rijeka [3] [19] was chosen as the basis for the research. The simulation traffic models of port terminals are based on the display of activities and/or technological processes of the real system or on the display of their desired state [12]. The advantage of using simulation tools in the port terminal area is the possibility of displaying at several levels individual activities in compressed time. The levels of individual activities or their sequences can be shown either separately or in their interaction at the port level or at the terminal itself or at the level of individual areas. The above-mentioned activities within the area of the terminal relate to:

- activities or technological processes for the acceptance of ships and other activities that are characteristic of the operational quay area,
- activities or technological processes that are characteristic of the warehousing or stowage area, and
- activities or technological processes that are characteristic of the container terminal delivery/dispatch area.

Simulation tools can also be applied in areas beyond the above defined areas that are closely interlinked in the realization of the entire process. Thus, the delivery/dispatch area of the terminal is closely connected to the network of routes permitting further freight transport, which is also the "core of the house" for the functioning of the whole system [3]. The assigned name is specific to the given area because inadequately implemented road connections network designing and planning procedures can lead to the congestion or bottlenecks and to prevented normal operation, no matter how well designed and planned its remaining segments. For this reason, the network of connections the container terminal of the port of Rijeka is closely linked to represents the object of this research [3]. The road traffic branch, despite the numerous directives and incentives of the European Union to reduce the share of its use, is still largely represented in the cargo dispatch and delivery owing to the fundamental characteristics of speed, efficiency, flexibility and elasticity. The "Brajdica" container terminal delivery/dispatch area is closely connected to the following road network that enables its connections with the gravity hinterland [3] [13]:

- motorway A6 (Zagreb-Rijeka) – European traffic route E65,
- motorway A7 (border crossing Rupa-Rijeka-Križišće-Žuta Lokva),
- Rijeka express road,
- state road D-404, te
- Container terminal „Brajdica" access roads.

The A6 and A7 motorways bring together the flows of inland road traffic routes, i.e. Central and Southern Dalmatia, while the A7 motorway is a direct link between the Rijeka port and the container terminal with the nearest border crossing of Rupa (the border with the Republic of Slovenia). The A7 motorway is currently only partially operational at the section of the border crossing of Rupa to Križišće, while the remaining part of the motorway section from Križišće to Žuta Lokva is expected to open in the near future. The most important roads to connect the container terminal to the hinterland are access roads and the state road D-404, which represent the most important road traffic infrastructure in the delivery and dispatch of containers from the terminal. The Rijeka express road with its segments in the direction of Trieste, Ljubljana, Zagreb and Split represents the artery of national, but also of wider international significance, what makes it part of the trans-European traffic network.[1] In order to eliminate the overload of city roads by HDV, the State Road D-404 was also built. The state road D-404 connects the Draga junction with the container terminal „Brajdica“ and the core city centre. For the container terminal itself, access roads to the terminal are also indispensable in order for the vehicles arriving from the direction of the Draga junction to be directed to the terminal and those going in the opposite direction to the Draga junction. With the construction of the connecting sections of the "Brajdica" container terminal traffic network of the corresponding throughput capacity resulted in the connection with the state road D-404, and thus in full separation of arrivals and departures of HDV from the city centre roads [3].

3. THE „BRAJDICA“ CONTAINER TERMINAL ROAD NETWORK IN THE FUNCTION OF A MICROSIMULATION TRAFFIC ANALYSIS

Microscopic traffic models are the basis of numerous computer simulation tools, and their use enables the study and description of traffic flows at individual levels or at the levels of particular entities (vehicles) in the traffic network [2] [4] [6] [14]. Microscopic traffic models are useful because the most detailed information can be collected by observing the relationship between vehicle behaviour at the individual level and observing vehicle behaviour and the surrounding environment [4] [14] [15]. There are numerous simulation tools characterized by the microsimulation traffic model, but, with regard to functions of the tools needed to elaborate the topic of this paper, the simulation tool of the PTV Group (Planung Transport Verkehr AG) under the name PTV Vissim will be used.

The process of developing a microsimulation traffic model is specific to each simulation tool and depends in particular on the complexity of the observed section of the traffic network, as well as on the problem for which an optimal solution is being sought [16]. The development of a microsimulation model requires a systematic approach because a functional model requires a large number of data to be collected and numerous traffic analysis-related activities to be conducted that are mutually dependent [8] [9]. To simplify the implementation of the key steps in the design of the microsimulation traffic model, a simplified flow-chart was created, which is the basis for modelling (Figure 1).

[1] https://www.arz.hr/hr/autocesta/dionice/rijecka-obilaznica (14.04.2019)

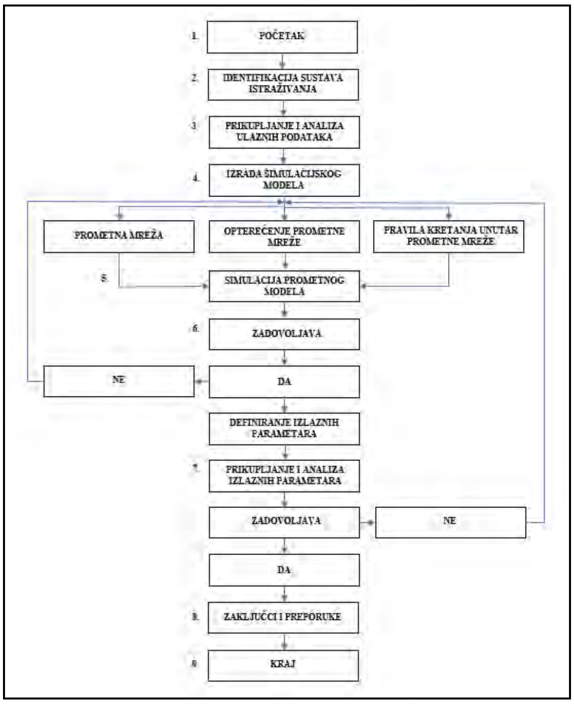

Figure 1 A simplified activities (steps) flow-chart for the development of microsimulation traffic model using the PTV Vissim simulation tool

Source: Created by authors

The second step in the development of the microsimulation traffic model is to define the observation area. In realizing this step, it is necessary to keep in mind the fact that taking into account a system section too large to study can have negative consequences on the results because it is very difficult to record and observe an extremely large number of interrelationships between the individual components of the system. For this reason, a separate segment of the observed system refers to the study of the access roads to the container terminal "Brajdica", including a separated section of the state road D-404. The focus of the research is primarily on the access roads to the container terminal, because their throughput capacity affects the possibility of undisturbed flow of container delivery and dispatch from the terminal, and thus the traffic flows on the state road D-404. The third and fourth steps of the flow chart refer to the collection and analysis of the required input parameters and to the development of a microsimulation traffic model divided into several sub-steps. The selected research area is divided into several key areas of observation requiring the collection and analysis of the input data important for the functioning of the microsimulation traffic model. The key areas of observation are the following (Figure 2):

- intersection R88 (Slavka Cindrića Str. – State road D-404)
- intersection R89 (Andrije Kačića Miošića Promenade – State road D-404)
- Access roads – Container terminal „Brajdica"

Figure 2 Key areas of observation of the traffic network selected segment

Source: Authors, using PTV Vissim microsimulation tool and AutoCAD

The input data required for the development of a functional microsimulation traffic model were collected separately for each selected key area of observation [17]:

- input data on traffic load,
- input data on possible directions of vehicle movement, and
- input data on signal plans (if they are stable).

Data on traffic loads and achieved travel directions for defined areas were collected from 1st January to 31st December 2018. The data were collected by detectors mounted on specific sections where a noticeable change in the traffic load caused by inflows or outflows from the traffic flow occurred. By means of analysis, the data were grouped in data sets for specific days of the week (Monday, Wednesday and Friday) depending on the vehicle class recorded. Input data for the two mentioned intersections were collected by the Rijeka traffic control centre (Rijeka promet d.o.o.) in charge of their management and control on the basis of their location within the city traffic network, while the traffic load data and the achieved driving directions of vehicles for the area of the access roads to the container terminal "Brajdica" were collected by Hrvatske ceste d.o.o. or the competent authority in charge of the management of that segment of the traffic network. The collected traffic load data had to be displayed as the traffic load mean value and reduced to one-hour observation level (3600 s). This data analysis provided a greater statistical reliability of input data with a view to displaying the usual daily traffic load and, based on these results, selecting the specific time period when the largest traffic load occurs. It was noted that in each of the key areas of observation the peak traffic load occurs between 15 and 18 hours (peak hours). The traffic load data recorded in the defined peak load hours were the input data in the design of the microsimulation traffic model.

The first key area of this microsimulation traffic model is intersection R88 (Figure 3) that represents the input point of the observed segment of section D-404, constructed as a three-leg level intersection. The intersection is equipped with the entire traffic flow time-controlled light signals with the cycle duration for the observed peak load time of 100 s. The signal plan of the intersection is regulated by four signalling groups designed for motorized traffic and four signalling groups for pedestrian traffic. Intersection R88 is also equipped with adequate traffic management horizontal signalling. The speed in the intersection zone is limited to 50 km/h.

Figure 3 Display of three-leg intersection R88 (Slavka Cindrića Street – D-404)

Source: Authors, using PTV Vissim microsimulation tool

The observed load expressed in the number of vehicles and PCE units per hour and the achieved vehicle travel directions through the intersection during the peak load hour are shown in Table 1.

Table 1 An overview of the average one-hour peak traffic load on the R88 intersection legs depending on the vehicle travel direction

INTERSECTION APPROACHES R88	VEHICLE CLASS	LEG 1 - Delta (veh./h)	PCE/h	LEG 2 - Hinka Bačića Str. (veh./h)	PCE/h	LEG 3 - Slavka Cindrića Str. (veh./h)	PCE/h
INTERSECTION APPROACH 1 - Delta	Passenger cars			600	630	755	796
	LDV – Light Duty Vehicles			8		6	
	HDV -Heavy Duty Vehicles			3		3	
	Buses			6		13	
INTERSECTION APPROACH 2 - Hinka Bačića Str.	Passenger cars	333	363			17	31
	LDV – Light Duty Vehicles	16				4	
	HDV -Heavy Duty Vehicles	3				4	
	Buses	0				0	
INTERSECTION APPROACH 3 - Slavka Cindrića Str.	Passenger cars	28	28	0	0		
	LDV – Light Duty Vehicles	0		0			
	HDV -Heavy Duty Vehicles	0		0			
	Buses	0		0			

Source: Authors, based on data collected by the ground traffic control centre of the City of Rijeka

According to the data from Table 1 it can be understood that according to the displayed concentration of vehicles in the observed peak load time, the highest load refers to leg 1 - Delta (main direction) with incoming traffic flow of 1426 PCE/h, where 630 PCE/h keep travelling straight ahead to leg 2 or to the Hinka Bačića Street while passing through the intersection (direction northwest-southeast), while the remaining 796 PCE/h turn to the left into leg 3, i.e. Slavka Cindrića Street. According to the data on the leg 2 inflow it can be seen that its load is 394 PCE/h, where 363 PCE/h keep travelling towards leg 1, i.e. in the direction of the Delta (the direction of the main roadway SE-NW) until 31 PCE/h turn right to leg 3, i.e. the Slavka Cindrića Street. The load at leg 3 is much lower and therefore is not considered relevant to the interpretation of traffic load data.

The second key area refers to the intersection R89 (Figure 4) located at a distance of 200 m from intersection R88 to the east. The intersection is also constructed at level with a total of four active legs and is equipped with time-steady control light signals over the entire traffic flow with the duration of the cycle at a peak load time of 100 s. The signal plan of this intersection is regulated by five signalling groups intended for motorized traffic and four signalling groups for pedestrian traffic. The R89 intersection is equipped with appropriate horizontal traffic management signalization, with the maximum speed allowed in the intersection area of 50 km/h as well.

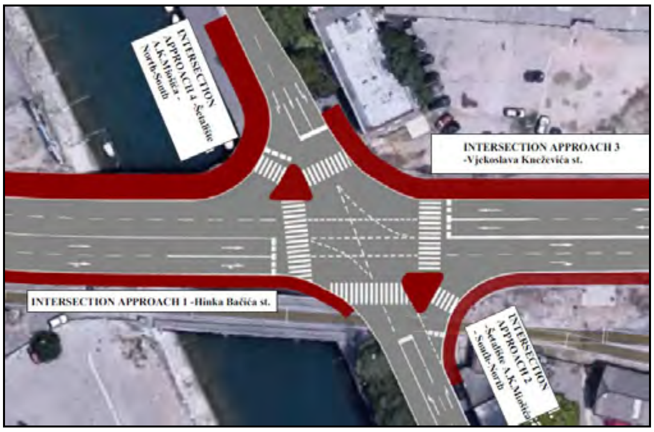

Figure 4 Display of four-leg intersection R89 (Andrije Kačića Miošića Str. – D-404)

Source: Authors, using PTV Vissim microsimulation tool

The observed load is expressed on the basis of the same procedure as for the preceding intersection R88 and is shown in Table 1.

Table 2 An overview of the average one-hour peak traffic load in legs of the intersection R89 depending on the vehicle travel direction

INTERSECTION APPROACHES R89	VEHICLE CLASS	INTERSECTION APPROACH 1 - Hinka Bačića Str. (veh./h)	PCE/h	INTERSECTION APPROACH 2- Andrije Kačića Miošića - S-N (veh./h)	PCE /h	INTERSECTION APPROACH 3 - Vjekoslava Kneževića Str. (veh./h)	PCE/h	INTERSECTION APPROACH 4 - Andrije Kačića Miošića - N-S (veh./h)	PCE/h
INTERSECTION APPROACH 1 - Hinka Bačića Str.	Pass.ger cars			12	22	588	608	0	0
	LDV – Light Duty Vehicles			4		4		0	
	HDV - Heavy Duty Vehicles			2		1		0	
	Buses			0		6		0	
INTERSECTION APPROACH 2 - Andrije Kačića Miošića - S-N0	Pass.ger cars	54	60			59	74	0	0
	LDV – Light Duty Vehicles	0				2		0	
	HDV - Heavy Duty Vehicles	3				6		0	
	Buses	0				0		0	
INTERSECTION APPROACH 3 - Vjekoslava Kneževića Str.	Pass.ger cars	258	29 6	0	0			0	0
	LDV – Light Duty Vehicles	20		0				0	
	HDV - Heavy Duty Vehicles	4		0				0	
	Buses	0		0				0	
INTERSECTION APPROACH 4 - Andrije Kačića Miošića - N-S	Pass.ger cars	38	38	46	55	207	218.5		
	LDV – Light Duty Vehicles	0		2		5			
	HDV - Heavy Duty Vehicles	0		3		2			
	Buses	0		0		0			

Source: Authors, based on data collected by the ground traffic control centre of the City of Rijeka

According to the displayed concentration of vehicles in the observed peak load hour the highest load refers to leg 1, i.e. the Hinka Bačića Street in terms of traffic inflow. The aforementioned inflow to leg 1 of 630 PCE/h is distributed after passing through the intersection in the direction of leg 2, i.e. the Andrije Kačića Miošića Street (S-N) at the rate of 22 PCE/h and of leg 3, i.e. the Vjekoslava Kneževića Street (W-E) at the rate of 608 PCE/h. The traffic inflow to leg 3 or the Vjekoslava Kneževića Street of 296 PCE/h is distributed after passing through the intersection at the rate of 296 PCE/h to leg 1 or the Hinka Bačića Street (direction of the main roadway E-W). In addition, leg 4 is also an important leg in terms of traffic load. The data on the vehicle inflow shown in the table point out that after passing through the intersection, 38 PCE/h follow the direction to leg 1, 55 PCE/h to leg 2, and 218.5 PCE/h to leg 3, i.e. the Vjekoslava Kneževića Street.

The access roads represent the underlying object or base of the research and due to their great importance they required necessarily to be explored and analysed in detail in order for all the specificities needed to be identified for the development of a functional microsimulation traffic model. The network of observed roads is located between the Pecine tunnel exit in the N-W direction or the Vjekoslava Kneževića

Street towards the city centre and, on the other side, the end of the Brajdica viaduct in the S-E direction or in the direction of the Draga junction. The network of access roads to the container terminal including the selected segment of the state road D-404 is shown in Figure 5.

Figure 5 Display of the access roads network including the selected segment of a section of state road D-404

Source: Authors, using PTV Vissim microsimulation tool

Looking from the direction of the Draga junction to the Vjekoslava Kneževića Street, the displayed D-404 road stands out with one single 3.50 m wide traffic lane with speed limit of 60 km/h on the entire route from the Draga junction to the Pecine tunnel exit. At a distance of approximately 25 m from the Pecine tunnel exit, the existing active traffic lane is divided in two traffic lanes, with the right (separating) traffic lane allowing vehicle turning to the right or allowing the outflow of vehicles moving from the direction of the Draga junction toward the "Brajdica" container terminal while the left traffic lane allows vehicles to keep the direction towards the Vjekoslava Kneževića Street or towards the city centre. The vehicles accessing the 3.50 m wide access road lane with a speed limit of 60 km/h and selecting the right traffic lane have the possibility to enter the "Brajdica" container terminal or, by selecting the left traffic lane, to make a U-turn for inclusion in the active traffic flow on state road D-404 in the direction of the Draga junction. In the opposite direction, i.e. towards the Draga junction, the D-404 road consists of one 3.50 m wide traffic lane with a speed limit of 60 km/h, allowing vehicle moving from the direction of the Vjekoslava Kneževića Street towards the Draga junction. In the same direction, about 70m from the Pecine tunnel entrance, the existing road is accessed by the traffic inflow from the 3.50 m wide traffic lane in the direction of the "Brajdica" container terminal (the direction of container terminal "Brajdica – Draga junction, Figure 5). As the traffic flow from the container terminal access road is introduced in the state road D-404 it does not entail any vehicle inflow to the existing traffic lane of the state road D-404 already occupied by vehicles coming from the direction of the Vjekoslava Kneževića Street, but the same travel direction is enabled through separate 3.50 m wide traffic lanes with a speed limit of 40 km/h.

In defining the input data on the traffic load according to certain classes of vehicles in the key area of observation, in addition to the data provided by Hrvatske ceste d.o.o. the data of the same characteristics were collected by the concessionaires of the container terminal "Jadranska vrata d.d." (*Adriatic Gate*). The collected data on traffic load obtained from the concessionaire "Jadranska vrata d.d." refer to the load of access roads in both directions by HDV arriving or leaving the area of the "Brajdica" container terminal in the period from 1st January to 31st December. The reason for collecting two groups of identical data is the possibility of their comparison due to the specificity and high importance of the selected area for the development of a microsimulation traffic model, in order to ensure for any deviations from the real presentation to be minimized and the statistical reliability increased. The analysis of two identical data sets of traffic loads found that traffic load distributions coincide in 97% of cases, while errors or data incompatibilities of 3% may be attributed to detector errors. Based on the analysis of the correspondence between the two sets of data, it was observed that the greatest load of access roads was recorded between 3 and 6 PM, at the same time as in the analysis of the traffic load data of the two analyzed intersections. For the reliability of the microsimulation model the data collected had to be reduced to one-hour average of all traffic loads recorded on the specific days of observation. Data on the traffic load of the observed area in relation to the defined directions that are expressed in the number of vehicles and PCE units depending on their class are shown in Table 3.

Table 3 The average peak hour traffic loads on the „Brajdica“ container terminal access roads in dependence on possible vehicle travel directions

AVAILABLE VEHICLE MOVING DIRECTIONS	VEHICLE CLASS	DIRECT.1 - Draga junction (veh./h)	PCE/h	DIRECT. 2 - Vjekoslava Kneževića Str. (veh./h)	PCE/h	DIRECT. 3 - Container terminal "Brajdica" (veh./h)	PCE/h
DIRECTION 1 – Draga junction	Passenger cars			258	296	33	113
	LTV – Light duty vehicles			20		0	
	TTV – Heavy duty vehicles			4		40	
	Buses			0		0	
DIRECTION 2 – Vjekoslava Kneževića Str.	Passenger cars	854	900.5			0	0
	LTV - Light duty vehicles	11				0	
	TTV - Heavy duty vehicles	9				0	
	Buses	6				0	
DIRECTION 3 – container terminal "Brajdica"	Passenger cars	14	94	0	0		
	LTV - Light duty vehicles	0		0			
	TTV - Heavy duty vehicles	40		0			
	Buses	0		0			

Source: Authors, based on data collected by the state road D-404 management authority and by the container terminal „Jadranska vrata“ concessionaire

According to the data presented in Table 3 it is noted that the greatest traffic inflow is recorded from the direction of the Vjekoslava Kneževića Street towards the Draga junction, precisely of 900.5 PCE/h. In addition to this, the traffic inflow from the direction of the Draga junction towards the Vjekoslava Kneževića Street is also worth mentioning due to the load of 296 PCE/h. The access road is loaded with the traffic inflow from the Draga junction towards the "Brajdica" container terminal reaching 113 PCE/h. The PCE unit value obtained is the result of the fact that 40 heavy duty vehicles and 33 passenger cars travel in this direction, with passenger cars travelling towards the container terminal use the return direction that provides them with the possibility of a U-turn. In the opposite direction, i.e. from the direction of the "Brajdica" container terminal towards the Draga junction the traffic inflow reaches 94 PCE/h or 40 heavy duty vehicles and 14 passenger cars. The procedures of input data collecting on traffic loads, realized vehicle travel directions, and signal plans are the basis for achieving the functionality of the microsimulation traffic model [17] [20]. However, in order to increase the reliability of the insight into the real or the existing state of the observed (selected) segment of the system, it is also necessary to define and integrate into the microsimulation traffic model any other elements that have a significant impact on the course of the simulation. The integration of influential elements within the model will result in certain influences on the behaviour of participating vehicles using the traffic network [20] [21]. As part of the computer aided simulation tool PTV Vissim i.e.

within the observed model, the following elements [17] [18] are defined: Desired Speed Decision, Reduced Speed Area, Conflict Areas, Priority Rules and Stop Signs. The first in a series of elements that affect the simulation of a microsimulation traffic model is the Desired Speed Decision on certain segments of the traffic network. The Desired Speed Decision labels are placed on the traffic lane of the developed traffic network and are marked by yellow line on the traffic lane. The element inserted within the microsimulation traffic model has an impact on vehicles until it reaches the next identical element of the model of the same functions [17]. The next element influencing the simulation of a traffic model is the Reduced Speed Area. This element affects the traffic flow within the observed network by reducing or adjusting the vehicle speed [17]. The previous element and this one are distinguished by the fact that the Reduced Speed Area applies exclusively to a certain length or a certain segment of the roadway while the Desired Speed Decision element applies to the entire road until it reaches the first next label of the element of the same properties. The adjusted speed area within the traffic model is marked with square labels of blue edges that follow the direction of the roadway. The third of the elements of influence that needs to be regulated to achieve a realistic view of the state refers to Conflict Areas. This element is regulated in level intersections of traffic flows [17]. The element is arranged within a model in such a way as to determine the main and secondary directions of vehicle course so that vehicles travelling along a particular roadway (direction) toward a crossing may react in time to allow, if necessary and if so arranged, vehicles travelling along the main or lateral roads (directions) surpass them. Conflict areas within the models are represented in the form of fully tinted squares. Considering the possible combinations of colours within a traffic model, the following combinations [17] appear: yellow-yellow, red-red, and green-red (and vice versa). The green-red (and vice versa) combination of conflict areas is of greatest importance to the design of the model because green marks the road or the main direction while red marks the secondary direction. The priority element is defined exclusively at the road level, not at the level of the conflict area as the previous element. This element is shown on the traffic lane in the form of a straight line coloured red and green. The red line indicates the secondary road or the secondary direction whereby the vehicle travelling in that direction is obliged to give priority to all vehicles that are approaching along the main direction i.e. the direction marked with a green line. The last defined element refers to the mandatory stopping. This element affects the model simulation insofar as the vehicle, with respect to the defined time based on a particular statistical distribution, must stop and remain idle [17]. The influencing elements here defined can be seen in the R89 intersection example (Figure 6).

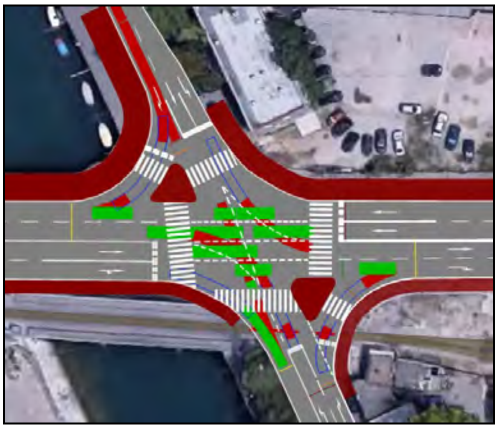

Figure 6 Graphic presentation of influencing elements defined in the area of intersection R89

Source: Authors, using PTV Vissim microsimulation tool

The fifth and sixth step of the microsimulation model flow-chart is related to the initiation of model simulation and its validation. The duration of the simulation is defined to 7200 s because the traffic load input data are related to an hour (3600 s) of observation. With the extended time of the simulation, it has become more likely that all vehicles arriving at the model within the range of 0-3600 will also leave. The simulation duration of 7200 s is divided into eight equal intervals of 900 s in order for the output parameters result follow-up to be as close as possible to the real-time presentation. If the vehicles do not leave the model within the 0-3600 interval, there are located areas of reduced traffic volume capacity within the traffic model (supply> demand). By repeating the simulation five times, the statistical reliability of the simulation output results is increased. The sixth step involves starting the simulation and observing its outcomes. By starting a simulation, it was stated for all the model elements herein defined to interact mutually and that the model corresponds to the existing state of the observed system segment. However, observing the course of the simulation based on the existing input data on traffic load during peak hours, the boundary throughput of the access road to the container terminal "Brajdica" from the direction of the Draga junction was noticed because the number of vehicles generated by random variables in the observation interval was exponentially increased. The problem rests in the fact that, in proportion with the increase in the number of HDV vehicles using the right traffic lane intended for access to the terminal, the number of queuing vehicles is also increased during the simulation, thus preventing the use of the left traffic lane intended for vehicles performing a U-turn for their return travel (mainly passenger cars) and inclusion into the active traffic flow on state road D-404 towards the Draga junction. The boundary throughput capacity was determined in the simulation time interval 3600-4200 s where it was noted that in such a short period of time the traffic flow is affected by such congestion, i.e. length of the queue on the access road that limits the active traffic flow on state road D-404. The problem is extremely significant for proper functioning of the city traffic network in future as well as the traffic of the whole region because the state road D-404 is the main artery linking the city of Rijeka and thus the container terminal with the rest of the country by means of express roads and motorways. The described problem in the defined simulation duration interval is presented in Figure 7.

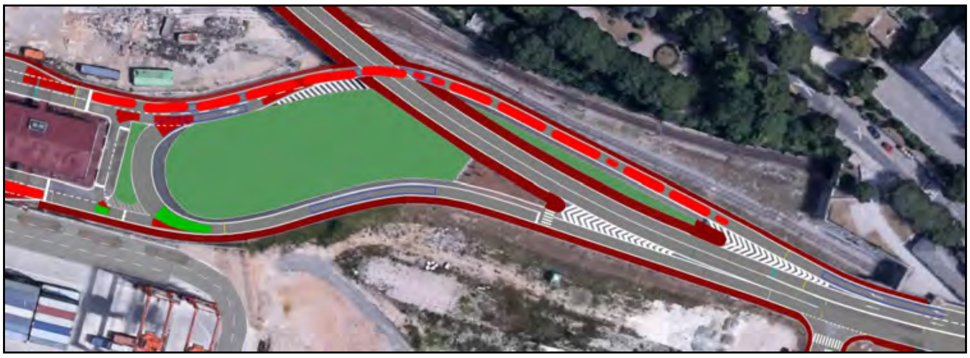

Figure 7 Presentation of congestion and boundary throughput of the access road (existing load) - Scenario 1

Source: Authors, using PTV Vissim microsimulation tool

The focal area of the research, for which the outflow observation parameters will be defined and adjusted, will be the access road to the "Brajdica" container terminal from the Draga junction to the terminal entrance. The defined outflow parameters of observations to be used for the quantification of the state of traffic situation are shown in Table 4 and Figure 8.

Table 4 Defined outflow parameters of the selected observation area

Data collection	Vehicle number detectors - Position	Colour
	1 – Draga junction – access road to Container terminal „Brajdica“	RED
	2 - Entrance – Container terminal „Brajdica“	
	3 - Access road (U-turn)	
	4 - Exit – Container terminal „Brajdica“	
	5 - Access road to Container terminal „Bradica“ – Draga junction	
	6 - Vjekoslava Kneževića Str. – Draga junction	
	7 – Draga junction – Vjekoslava Kneževića Str.	
Vehicle travel & delay time	Vehicle travel time and delay time detector – Distance between starting and ending defined point (m)	Start - GREEN; End - YELLOW
	1 - Vehicle travel time and Delay time - 293,89	
	2 - Vehicle travel time and Delay time - 304,28	
	3 - Vehicle travel time and Delay time - 235,38	
Queue length	Queue detector position	BLACK
	1 - Queue length - entrance - Container terminal "Brajdica"	
	2 - Queue length - exit - Container terminal "Brajdica"	

Source: Created by authors

Figure 8 Display of defined elements needed for the collection of results of outflow parameters

Source: Author, using PTV Vissim microsimulation tool

In the next chapter a detailed analysis is elaborated of the collected results of outflow parameters derived from the simulation of the existing state of the traffic model and the application of the "what if" analysis is presented in order to assess the access road throughput in the future period.

4. AN ANALYSIS OF OUTCOMES AND THE PERFORMANCE OF THE „WHAT IF“ ANALYSIS BASED ON A MICROSIMULATION TRAFFIC MODEL

Since the problem of congestion on the access road to the container terminal "Brajdica" was identified by simulation of the traffic model based on the input data of the existing situation, it was necessary for such a situation to be presented quantitatively and the detailed analysis of the observed parameters to be elaborated. Once the results of the analysis of the output parameters are obtained, there are two interrelated questions to be raised: "Are the results of the output parameters obtained by the simulation of scenario 1 random with respect to the stochasticity of the observed system and the generation of arrivals based on the value of the random variables?" and "Is the throughput of the access road adequate if exposed to a greater traffic load?". Answers to these questions can be obtained by implementing additional scenarios to be based on higher values of the input parameters on the traffic load of the selected and/or observed area by implementing the "what if" analysis. The basis for implementing the "what if" analysis was the already developed traffic model, yet of different values of input parameters. In order to obtain the basis for increasing the values of the input parameters, it was necessary to define the relationship between the two sets of data that were mutually dependent. The research carried out showed the dependence of two sets of data related to the container terminal turnover rate and the number of heavy duty vehicles accessing the terminal area by access roads. Both sets of data are directly correlated, meaning that the container terminal turnover rate directly affects the number of heavy duty vehicles and vice versa. The analysis showed that the number of heavy duty vehicles was increased in proportion with the increase in the turnover of the container terminal "Brajdica", whereby it was assumed that this increase in observed data sets caused no change in the shares of transport modes involved in the delivery and/or dispatch of containers on the container terminal "Brajdica". The "what if" analysis was conducted applying the input data of the traffic load related to HDV that are proportional to the increase in the terminal container turnover up to 250,000 and 300,000 TEUs. The "what if" analysis implementation procedure was based on the values of the input data on traffic loads attributed to TTV as shown in Table 5.

Table 5 Increase in the number of TTV in particular directions of the selected observation area

			PRESUMED NUMBER OF HDV	
SCENARIO	YEAR	CARGO TURNOVER OF CONTAINER TERMINAL „BRAJDICA“ (TEU)	Direction – Entrance (Draga junction – Container terminal „Brajdica“	Direction – Exit (Container terminal „Brajdica“ – Draga junction)
1	2018	222.657	40,00	40,00
2	-	250.000	46,00	46,00
3 – control scenario	-	300.000	53,00	53,00

Source: Authors, based on data provided by competent authorities

In the next chapters of this paper the analysis is presented of the outcome of output parameters of the simulation performed in respect of the existing load (Scenario 1) and the remaining scenarios that had to be performed, all of them based on the above presented input values of the TTV traffic loads.

4.1. Analysis of the results of output parameters of the performed scenario 1 – actually present traffic load

The sequence of the analysis of the collected results of the set of output parameters was carried out in dependence on their significance for concrete conclusions. It is important to note that the sets of simulation results are presented in average values to obtain results of greater statistical significance considering the same data obtained from five consecutive simulations. The sets of average values of the output parameters were observed and analyzed with respect to their fundamental characteristics and with respect to each simulation interval for their more precise analysis and concrete conclusions.

Table 7 Results of the performed simulation of scenario 1

		Simulation 1 - time intervals [s]							
	Det. No.	0-900	900-1800	1800-2700	2700-3600	3600-4500	4500-5400	5400-6300	6300-7200
Data collection detectors [No.of.veh.]	1	17.00	17.00	17.00	13.00	7.00	0.00	0.00	0.00
	2	5.00	6.00	5.00	7.00	6.00	6.00	4.00	0.00
	3	6.00	7.00	3.00	6.00	3.00	4.00	2.00	0.00
	4	7.00	9.00	8.00	8.00	7.00	6.00	0.00	0.00
	5	13.00	15.00	12.00	14.00	10.00	10.00	2.00	0.00
Vehicle travel time [s]	1	183.97	505.29	780.18	1200.22	1603.00	1852.33	1982.52	1158.22
	2	38.01	301.15	485.77	1018.56	1372.49	1547.65	1750.01	930.52
	3	25.49	24.85	25.86	25.56	26.51	25.39	0.00	0.00
Vehicle delay time [s]	1	155.96	477.60	752.58	1172.40	1575.07	1824.30	1954.88	0.00
	2	15.79	278.92	463.16	996.22	1350.46	1525.37	1727.82	0.00
	3	1.99	1.65	2.58	1.78	1.53	2.12	0.00	0.00
Queue length [m]	1	45.11	107.02	220.00	360.97	311.83	156.71	37.06	0.00
	2	60.99	137.54	149.90	173.29	135.95	28.18	0.00	0.00

Source: Created by authors

The analysis of the average number of vehicles travelling within the defined areas of detector-aided measurements within the interval of 900 s has no major significance for precise conclusions, but is used solely as a control parameter to prove the distribution of vehicle arrivals within the observed segment of the traffic model with respect to the selected simulation time intervals. However, it is noticed that just within the first four intervals the highest throughput or the largest number of travelling vehicles was recorded, whereas at further simulation intervals the number of vehicles decreased, what can be associated with greater congestion and inability to travel through the specific section of the road. Furthermore, it is important to show the correlation of vehicle arrivals within the defined interval and their outflow. As previously defined, vehicles enter the traffic network within the interval of 0-3600 s, and the set simulation duration of 3600 s is not sufficient for all vehicles travelling within the same model to leave. According to the data obtained by detector 2 it is noticed that due to the congestion of the access road from the direction of the Draga junction towards the container terminal, the last vehicle travelling was recorded as late as in the interval 5400-6300 s. As a consequence, the greater average vehicle travel time within the traffic network and the delay caused by interruptions. It is also necessary to emphasize approximately the same number of vehicles on detector 2 as a result of stopping time at the terminal entrance needed for the fulfilment of certain administrative requirements of an estimated average duration of 180 s with departure of 30 s. The correlation of this parameter with the others is reflected in the fact that in case the generation of accidental vehicle arrivals results in a larger number of vehicles than the observed roads can allow, it will result in a proportional increase in the average travel time of vehicles on the observed segment of the network. The results for the average travel time of vehicles from/to the defined sections were obtained by recording the average travel time of the randomly selected vehicle sample. The table apparently shows that the results of the observed output parameter increase proportionally with the duration of the simulation, that is, that at each interval the average travel time of the vehicle increases by an average of 299.75 s on the time travel detector 1, and by 285.33 s on the time travel detector 2, while the time detector 3 recorded a decrease in the average travel time within each subsequent observation interval by 1 s. The reason for the increase in the average travel time of vehicles through the traffic network is the accumulation of vehicles on the observed segments, while the reduction of the travel time recorded by detector 3 is attributed to the adequate throughput of the roadways that allow for vehicle travelling from the direction of the container terminal toward the Draga junction. The analysis performed shows that the maximum travel time of 1982.52 s on detector 1 was recorded in the seventh simulation interval (5400-6300 s) or the 33 min minimum travel time on the observed detector, while with respect to the defined simulation influencing elements and the configuration of the traffic network the travel time of 183.96 s or 3.06 min was recorded in the initial interval. The increase in the average vehicle travel time on detector 2 is highly specific because it is exclusively the consequence of the congestion of the access road traffic lane in the direction of the container terminal due to the TTV queuing for entry into the terminal. This was the evidence of the congestion that prevented passenger cars from U-turning using the left traffic lane intended for this purpose and to continue to travel in the direction of the Draga junction. In this accordance it can be concluded that the increase in the average travel time of vehicles on the observed segments of the traffic network is the result of the correlation between the currently analyzed parameter and concentration of the number of arrivals or accumulation of vehicles on the observed segments of the traffic network. The results of the output parameters of the average vehicle delay in the traffic network are directly correlated with the previously analyzed output parameter. The vehicle delay in the traffic network results from the difference between the theoretical or ideal and the realistic travel time of a vehicle between the preset initial and end detectors used for the measurement. The results of vehicle delays on detectors 1 and 2 indicate a proportional increase in travel time at each subsequent simulation time interval. In this case, no vehicle delay was recorded on detector 3 because the ideal travel time between the initial and final travel detector 3 is equal to the travel time achieved. The average vehicle delay recorded by detector 1 is increased by an average of 299.82 in each of the subsequently observed simulation time intervals. The maximum delay of vehicles approaching the entrance to the container terminal and passing through detector 1 was recorded in the seventh simulation interval and was 1954.88 s. Accordingly, the minimum delay of vehicles was recorded in the first simulation interval and was 155.96 s. The significant vehicle delay interval results from numerous constant changes in the current travel modes on the observed segments of the network and precisely due to the occurrence of the boundary throughput. The last interpreted Scenario 1 parameter refers to the average length of the vehicle queue recorded on the specific sections of the observed segment of the traffic network within each of the simulation intervals. According to the data it is apparent that the features of the observation of said parameter were directed to recording the average and maximum achieved length of the vehicle queue on the observed detectors or specific sections of the traffic network. The queuing line length depends on the number of vehicles of different classes and it is therefore difficult to determine the average number of heavy duty vehicles and the number of remaining classes in the queue. The average length of the vehicle queue is particularly prominent in the detector 1 measuring area or on the traffic lane that allows the HDV to enter the terminal that equals, with regard to the simulation time intervals, 176.96 m. The average maximum length of the vehicle queue in the mentioned area of observation by detector 1 equalling 360.97 m is recorded in the interval of 2700-3600, whereby it can be concluded that the number of vehicles that had entered the model in previous intervals was greater than the number of vehicles that have left. The average increase in the vehicle queue in the recorded intervals is 105.29 m, while the average reduction in the vehicle queue in the intervals recorded is 107.97 m. On the other hand, it can be seen on detector 2 relating to the length of the vehicle queue at the terminal exit that the average length of the queue is 114.31 m, with an average increase or decrease in the queue in the recording intervals of 37.43 m and 72.56 m respectively. The cause of the above-mentioned problem concerning the length of the vehicle queue in the access road in the direction of the container terminal can be attributed to a number of stoppages or changes in the conditions of vehicle travel that reduce the possibility of vehicle flow on the selected segment of the road network. The constant increase in the length of the vehicle queue can be explained by the accumulation of vehicles on a selected segment of the traffic network caused by the boundary throughput.

The access road throughput is satisfactory until the occurrence of the overload during the peak hours of vehicles' arrival at the container terminal. At that point, the number of vehicles on the access road is much higher than the throughput rate. Hence the occurrence of vehicle accumulation and increase in any other values of the observed and analyzed parameters. Based on the analysis carried out, it is possible to confirm the previously identified problem that the throughput of the access road is borderline, that the congestion in the specific interval is constant and that it occurs in a way preventing even in a short interval of time the realization of the traffic flow on state road D-404 from the direction of Draga towards the Vjekoslava Kneževića Street. Taking into account the operation of the container terminal in the future, it is of essential importance to provide answers to the questions put in the beginning of this chapter in order to demonstrate that the conclusion of the borderline throughput of access roads is not the result of generating accidental vehicle arrivals within the model and whether the access road will be able to respond to future assumed loads. The proof will be achieved precisely by realizing the simulation of scenario 2 where the model traffic network is still identical to that in scenario 1.

4.2. Analysis of the results of scenarios 2 and 3 output parameters – the „Brajdica“ container terminal access roads load at the terminal turnover of 250.000 or 300.000 TEUs

Scenario 2 of this traffic model is based on the values of the concentration of vehicles of 46 TTV/h arriving from the direction of the Draga junction towards the "Brajdica" container terminal or 45 TTV/h arriving from the direction of the container terminal towards the Draga junction obtained by the assumption of the number of TTVs increasing in dependence on the increasing container turnover on the terminal to 250,000 TEUs. The implementation of this scenario provided a solution to the questions raised regarding the borderline throughput of the access road in the direction of the container terminal "Brajdica" and to the question of generating such values of the random variable on vehicles arrivals, i.e. that the borderline throughput recorded in a short time interval was only an accidental event. The outcomes of scenario 2 output parameters of this model are shown in Table 8.

Table 8 Results of the scenario 2 simulation performance

		Time interval of simulation [s]							
	Det. No.	0-900	900-1800	1800-2700	2700-3600	3600-4500	4500-5400	5400-6300	6300-7200
Data collection detectors [No.of.veh.]	1	19.00	19.00	12.00	10.00	9.00	2.00	0.00	0.00
	2	6.00	6.00	6.00	6.00	6.00	6.00	6.00	1.00
	3	6.00	4.00	4.00	3.00	5.00	5.00	1.00	0.00
	4	7.00	8.00	8.00	8.00	7.00	5.00	0.00	0.00
	5	12.00	13.00	13.00	11.00	11.00	11.00	1.00	0.00
Vehicle travel time [s]	1	228.02	648.23	1067.73	1451.09	1944.15	2021.91	1946.61	2174.30
	2	71.84	456.11	853.15	1290.93	1626.02	1605.74	1733.61	0.00
	3	25.79	25.67	25.89	25.54	26.88	25.81	0.00	0.00
Vehicle delay time [s]	1	200.02	620.57	1040.17	1423.38	1916.24	1993.78	1918.57	2146.20
	2	49.56	433.86	830.71	1268.77	1603.71	1583.24	1711.36	0.00
	3	1.99	1.95	2.32	1.80	1.83	1.85	0.00	0.00
Queue length [m]	1	64.40	163.29	348.10	478.13	390.69	204.00	74.92	3.39
	2	72.79	156.84	170.94	185.03	133.80	30.38	0.00	0.00

Source: Created by authors

The result of the output parameter on the number of vehicles on defined sections suggests that, based on the recording of the number of vehicles, the largest number of arrivals was also recorded in the first two intervals of the simulation of the traffic model while over time the number decreased. The largest number of vehicle travels was recorded on the detectors at the first simulation intervals due to the high traffic network throughput and the active realization of the traffic flow while during the simulation the number of vehicle arrivals in the model diminished due to the congestion that was exponentially increasing. It is obvious that the number of vehicles on the observed detectors was still large even after the simulation time of 3600 s. By comparing the results of the parameter with the results of the previously performed simulation, it is observed that following the increase in the number of vehicles within this scenario a proportional increase was also recorded in the number of vehicles that did not leave the model network within the envisaged 3600 s interval due to the congestion. All vehicles within the model arrived within the range of 0-3600 s and consequently it was impossible to observe the simulation at the one-hour observation level because the congestion shown by the simulation of this scenario was more pronounced than that observed by the simulation of scenario 1. The congestion was also proven by the fact that during the defined simulation time (7200 s) a total of 14 vehicles was recorded that were not able to pass through the specific road section at the point where detector 1 was located. The traffic load rate of the access road recorded by the scenario simulation 2 and the inability to realize the traffic flow in the direction of container terminal "Brajdica", and also in the direction of the Vjekoslava Knezevića Street, appeared already after 1500 s of the model simulation (Figure 9).

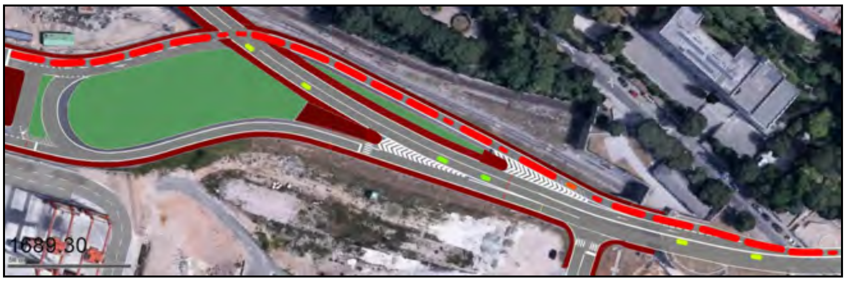

Figure 9 Presentation of the access road congestion or borderline throughput – Scenario 2

Source: Authors, using PTV Vissim microsimulation tool

The recorded congestion shown by the implementation of this scenario also causes a significant increase in the average travel time of vehicles in the observed segment of the traffic network. Based on the results of the average travel time of a vehicle through the network it is possible to note that the HDV travel time increases by an average of 278.04 with each simulation interval while average vehicle travel time on detector 2 increases by an average of 276.96 s. It is noticeable that the average vehicle travel time recorded by detector 1 in simulation intervals of 5400-6300 s is shorter than in other intervals and is again increased in the next interval. The reason is the arrival of vehicles during that simulation interval that is no longer constant and thus the average vehicle travel time decreases until the next interval in which there is no accumulation of vehicles in the travel time recording area that had previously reached the network but failed to pass through the detector 1 starting point of measuring. By comparing the results of the two scenarios, the same upward trend is observed in the travel time in each of the observed simulation intervals. However, the differences are significant in the values of the results of this scenario compared to the results of the present state scenario, where a comparison makes it apparent that the results of the average travel time of vehicles at detector 1 were by 277.04 higher than the results obtained by simulation of scenario 1 and by 160.54 s higher than the results of the average travel time recorded on the measuring detector 2. The average vehicle delay on the observed segment of the traffic network that was achieved by changing values of the input parameters indicates that the least average delay of a vehicle in the network was recorded in the initial simulation period or in the interval of 0-900 s and it was 200.02 s on detector 1 or 49.56 s on detector 2.

Comparing the average vehicle delay of this scenario with the previous vehicle delay scenario, the vehicle delay increase by 44.06 seconds or 33.77 s was recorded that had occurred within the first simulation interval. The maximum vehicle delay was recorded at detector 1 in the last simulation interval, i.e. 2146.2 s. The cause is identical to the result of the output parameter of the average travel time of the vehicle through the observed segment of the network. By each simulation interval the average vehicle delay within the model increases by 278.03 s on the average on detector 1 and by 276.97 s on detector 2. By comparing this with the previous scenario, the average vehicle delay achieved at each simulation interval results in 276.97 s on detector 1 and 26,90 s on the measuring detector 2. By analyzing data on the average vehicle queue length, the maximum mean lwength and the maximum vehicle queue length were recorded in the detector 1 measuring area. Accordingly, the largest vehicle's average length of 478.13 m was achieved in the simulation time interval of 2700-3600 s. By measuring by detector 1, the average increase in the vehicle queue by 137.91 m was observed within the first four intervals (simulation time of 0-3600 s) i.e. the average reduction of the vehicle queue by 118.68 m within the remaining four simulation intervals of 3600-7200 s. The results of this change in the observed parameter are closely associated with the fact that vehicle entry within the observed model is defined by the interval of simulation duration of 0-3600 s. By comparing the results of the observed parameter with the results of scenario 1, an increase in the average length of the queue on the access road in the direction of the terminal equals 117.16 m. This is the cause of the already described congestion or inability to realize the traffic flow of the access road and thus the realization of the normal traffic flow on state road D-404.

Based on the performance of this scenario, a final conclusion is made in respect of the two questions raised in the beginning of this chapter. Regarding the borderline throughput of the access road, it has been confirmed that the borderline throughput of the access road observed during the simulation of scenario 1 is not attributable to the generation of a random variable through which the vehicles enter the model at very small intervals, thus causing congestion. It is concluded that the borderline throughput of the access road results exlusively from its inadequate design throughput in respect of the existing one, but also in respect of the traffic load increase the implementation of scenario simulation 2 was based on. Simulation of scenario 2 also shows the value of the "Brajdica" container terminal turnover at which such a congestion of the access road in the direction of the container terminal "Brajdica" will occur and also that due to the traffic load caused by the HDV the access road throughput is completely inadequate and any normal traffic flow on state road D-404 is endangered. Based on the results of the output parameters of scenario 2, it has been confirmed that the aforementioned consequences caused by an increase in traffic load will occur at a time when the traffic of the container terminal reaches 250,000 TEU per year.

Previously presented data on the traffic load at the terminal annual turnover of 300,000 TEU were used to implement the third scenario of the microsimulation traffic model. Simulation of Scenario 3 was exclusively a control simulation that confirmed the correctness of the conclusion reached on the moment of realization of the complete impossibility of realizing the normal traffic flow in the selected area observed. Implementation of scenario 3 is based on the input values of the traffic load of 53 TTV/h travelling from the Draga junction towards the container terminal or 53 TTV/h travelling from the direction of the container terminal towards the Draga junction that were obtained using the above described procedure for assuming the container turnover at the terminal of 300,000 TEU per year. The simulation of scenario 3 resulted in the output parameters that showed that they increase in accordance with the traffic load increase. Thus, the highest value of the average travel time of vehicles on the observed segment of the traffic network was recorded in the measuring area of detector 1 at a value of 2127.79 s that, compared to the results of the highest average travel time of scenarios 1 and 2, exceeds them by an average of 49.38. In addition, with respect to the result of the implementation of scenario 3 concerning the average vehicle delay, which is closely related to the vehicle average travel time, it was found that the average increase in the mentioned parameter by 49.65 s exceeds the mean values obtained by the realization of scenarios 1 and 2. The last and most important decision making parameter refers to the average and maximum length of the queue of vehicles on the access road in the direction of the container terminal "Brajdica". Comparing the results it is apparent that the average length of the queue obtained by implementing scenario 3 exceeds by 15.53 m the queue length obtained by implementing scenario 2 and by 132.69 m the queue obtained by implementing scenario 1.

By implementing a scenario of the assessment of the load of the segment of the network observed it has been proved that, provided that no adequate measures are taken to reconstruct or upgrade the existing parts of the observed network, the problem of complete congestion will be reached very soon. It is also important to note that the identified congestion of the access road as well as the inability to carry out the adequate traffic flow on state road D-404 may be expected at a time when the terminal turnover rate reaches 250,000 TEU per year, if no reconstruction or upgrading is to be carried out. Consideration should also be given to the fact that the results of the scenarios that served as the basis for the above conclusions to be made were analyzed solely during peak hours and consequently the congestion and inability to run the traffic flow is also expected in that part of the day. Concerning the running of the functional traffic flow, for the remaining time of the day it is concluded that the throughput is satisfactory with respect to the traffic load that was then recorded and consequently no further traffic analysis was carried out.

5. CONCLUSION

The basic assumption of this research is that in the planning of the construction of access roads their existing and also the future throughput is able to take over the existing as well as future traffic load in accordance with the increase in the turnover of the container terminal "Brajdica". However, after many years of container turnover growth, the throughput of the access roads has reached the upper limit and its efficiency in the future is very questionable. For this reason, using a microsimulation tool PTV Vissim, a survey has been carried out to determine what access road loads need to be realized since otherwise, given the increase in the terminal container turnover, they would be completely congested and dysfunctional in terms of their primary purpose. The results obtained by increasing the loads of access roads are based on the implementation of three scenarios of the "what if" analysis. The implementation of scenario 1 showing the current load condition of the access road to the container terminal has led to conclusions on what output parameters need to be defined in order for the situation of the micro simulation traffic model to be quantified. The recorded results of the output parameters were primarily related to the average number of vehicles, average vehicle travel time, average vehicle delay within the traffic network, and the average and maximum length of the vehicle queue. By analyzing the observed output parameters, it was concluded that the throughput of access roads directing the vehicles from the container terminal towards the Draga junction and from the Draga junction to the container terminal is appropriate considering the existing load with heavy duty vehicles for the entire duration of the average daily load until the load peak hours or until a larger number of heavy duty vehicles accumulate on the access road to enter the terminal area in a short time interval. In such a case, the length of the vehicle queue makes it impossible for the left separating lane to be used, mostly by passenger cars, for the return travel towards state road D-404 or Draga junction. It has been proved by simulation that the throughput of the access road for the existing traffic load is boundary as confirmed by the fact that during the simulation the congestion grew to the extent that a very short section of the interval recorded the completely prevented realization of the traffic flow of vehicles directed to the state road D-404 towards the Vjekoslava Kneževića Street. In order to confirm or rebut the thesis of the access road inadequate or borderline throughput, and to determine whether the congestion results from the generation of such a random vehicle arrival rate scenario 2 was examined based on input parameters on the assumed number of heavy duty vehicles according to the annual increase in the "Brajdica" turnover to 250,000 TEU per year. Simulation of the model shows that the congestion or the length of the queue on the access road is much greater than the one achieved by simulation of scenario 1. The created queue length does not only prevent vehicles from entering the access road in the direction of the container terminal but completely prevents the realization of the normal traffic flow of vehicles travelling along the state road D-404 from the direction of the Draga junction to the Vjekoslava Kneževića Street or the city centre.

Having implemented and analyzed the results of scenario 2, it was finally concluded that the access roads, and thus the state road D-404 as well, would be fully congested during peak traffic loads, i.e. as soon as an increase in the number of vehicles occurs in compliance with the container terminal turnover of 250,000 TEUs per year. In order for the observed situation not to be only the result of accidental generation of intensive vehicle arrivals within the traffic model, it was necessary to conduct and analyze the results of the output parameters obtained by the implementation of scenario 3. Simulation of scenario 3 is exclusively a control simulation for the final conclusion to be based upon. Inputs on the number of heavy duty vehicles are assumed with regard to the container terminal annual turnover growth worth 300,000 TEUs. By implementing and analyzing the results of this scenario, it was confirmed that the congestion of the access road and the state road D-404 as recorded in scenario 2 was not only apparent or persistent for a relatively short period of simulation duration. It is concluded that if the realization of the concrete reconstruction of the access road does not take place until the moment the container turnover of 250,000 TEU - 300,000 TEU has been reached by the terminal, the problem will not only grow in terms of operational efficiency of the terminal but will also affect the disruption of the normal flow of vehicle traffic on the road D-404 to become not only a problem solely for the local area, but also for the regional one with the state road D-404 occupying the position of the basic artery within the traffic system.

REFERENCES

[1] Florian, M., Mahut, M., & Tremblay, N. (2008). Application of a simulation-based dynamic traffic assignment model. European Journal of Operational Research, 189 (3), 1381–1392. DOI:10.1016/j.ejor.2006.07.054

[2] Čerić, V. (1993). Simulacijsko modeliranje, Školska knjiga, Zagreb

[3] Vilke, S., & Krljan, T. (2017). Forecast for Lorry Traffic – Example of State Road D – 404 in Rijeka City. Journal of Maritime & Transportation Science, 53 (1), 67–83. doi:10.18048/5305

[4] De Dios Ortuzar, J., & G. Willumsen, L. (2011). Modelling Transport (4th Edition), John Wiley & Sons, Ltd. DOI: 10.1002/9781119993308

[5] Nasuha, N. & Rohani, M. (2018). Overview Of Application Of Traffic Simulation Model, MATEC Web of Conferences 150, 03006, January. pp. 1-5.

[6] Sun, J., Ma, Z., Li, T., & Niu, D. (2015). Development and application of an integrated traffic simulation and multi-driving simulators. Simulation Modelling Practice and Theory, 59, 1–17. DOI:10.1016/j.simpat.2015.08.003

[7] Mathew, T. (2014). Cell Transmission Models, Transportation Systems Engineering. IIT Bombay, 2014.

[8] Maria, A. (1997). Introduction to modeling and simulation. Proceedings of the 1997 Winter Simulation Conference, Atlanta, Georgia, U.S.A, 7-10 December. pp. 1-19.

[9] Barceló, J. (Ed.). (2010). Fundamentals of Traffic Simulation. International Series in Operations Research & Management Science. DOI:10.1007/978-1-4419-6142-6

[10] Delitala, M., & Degond, P. (2008). Modelling and simulation of vehicular traffic jam formation. Kinetic and Related Models, 1 (2), 279–293. DOI:10.3934/krm.2008.1.279

[11] Comert, G. (2013). Simple analytical models for estimating the queue lengths from probe vehicles at traffic signals. Transportation Research Part B: Methodological, 55, 59–74. DOI:10.1016/j.trb.2013.05.001

[12] Tomašević, M., Jadrijević, N. & Dundović, Č. (2011). The analysis of the container traffic movement in the Port of Rijeka compared to the container traffic in the Port of Koper. Scientific Journal of Maritime Research, 25/2, pp. 469-485

[13] http://www.mppi.hr (16.06.2019)

[14] Sun, D., Zhang, L., & Chen, F. (2013). Comparative study on simulation performances of CORSIM and VISSIM for urban street network. Simulation Modelling Practice and Theory, 37, 18–29. DOI:10.1016/j.simpat.2013.05.007

[15] Saidallah, M. & Elbelrhiti Elalaoui, A. (2016). A Comparative Study of Urban Road Traffic Simulators, MATEC Web of Conferences, ICTTE 2016, 81, pp. 1-6.

[16] Hunter, M., Fujimoto, R., Suh, W., & Kim, H. (2006). An Investigation of Real-Time Dynamic Data Driven Transportation Simulation. Proceedings of the 2006 Winter Simulation Conference. DOI:10.1109/wsc.2006.323242

[17] PTV Vissim 9.0. (2016). User Manual. PTV AG. Karlsruhe, Germany

[18] Schreckenberg, M., Neubert, L., & Wahle, J. (2001). Simulation of traffic in large road networks. Future Generation Computer Systems, 17 (5), 649–657. DOI:10.1016/s0167-739x(00)00033-9

[19] Karlić Mujo, H. (2009). Container Traffic in the Adriatic with Special Attention to the North Adriatic Ports. International Journal of Maritime Science & Technology "Our Sea", 56 (1-2), pp. 16-25.

[20] Yannes, C. D., & Lownes, N. E. (2010). Driver behaviour considerations in calibrating microsimulation models for capacity. International Journal of Society Systems Science, 2 (1), 84. DOI:10.1504/ijsss.2010.031468

[21] Shafiee, K., Lee, J. B., Leung, V. C. M., & Chow, G. (2011). Modeling and simulation of vehicular networks. Proceedings of the First ACM International Symposium on Design and Analysis of Intelligent Vehicular Networks and Applications - DIVANet '11. DOI:10.1145/2069000.2069014

FORECASTING CRUISE PASSENGER DEMAND IN MEDITERRANEAN CRUISE PORTS

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Summary

This paper presents two forecast methods for cruise passenger movement in the Mediterranean area. We examine the forecast method that can provide the most accurate prediction of passenger movement by analyzing the STL and SARIMA method. Based on the accuracy analysis, we find that STL is more accurate. The results of this study could be helpful for predicting short-term variations in passenger demand in the cruise ports of the Mediterranean region.

Keywords: cruise ports, passengers, forecast, Mediterranean

1. INTRODUCTION

When planning passenger terminal facilities, expected traffic flows, passenger demand, and cruise market growth should be considered to prevent injudicious infrastructure investments (oversized buildings). Therefore, accurate forecasting of passenger flow at ports is crucial to construct passenger facilities as well as for passenger flow management.

Forecast methods can be used to estimate the concept and size of required cruise terminal facilities, ground access, transport connections, and infrastructure. Infrastructure investments are strategic decisions made by port authorities to predict required facilities and expected traffic flows for the short term. It is important to have reliable forecasting and monitoring models to successfully manage traffic flows in cruise passenger terminals and for planning port facilities. The inability to forecast passenger volume in ports can lead to uncertainty in investment decision making. Consequently, ill-planned infrastructure investments can lead to large financial losses.

Decision makers (port authority) have no reliable tool to forecast passenger traffic, allowing them to design and implement the appropriate infrastructure. In recent years, many techniques have evolved that enable forecasting of traffic flows. There are several papers in the maritime sector alone related to the methods for forecasting traffic. (Schulze & Prinz, 2009) forecasted container transshipment in Germany using seasonal autoregressive integrated moving average (SARIMA) and Holt-Winters exponential smoothing approach. The results indicate that SARIMA's predictive performance is better than that of exponential smoothing. (Peng & Chu, 2009) compared six univariate models to forecast container throughput volume in three major Taiwanese ports and concluded that the classical decomposition methods and SARIMA give the best forecasts based on the accuracy criterion used. A different approach was followed by Cleveland et al. (1990) who developed seasonal-trend decomposition using Loess (STL) which became quite popular. This method uses iterative local regression (LOESS) smoothing to obtain a trend estimate and extract a changing additive seasonal component (Dokumentov & Hyndman, 2015).

In this paper, we compare two forecast methods: STL and SARIMA, in which the future value of a time series is forecast based on past values. This study answers the following research questions. Which forecast model is more reliable for short-term forecasting of cruise passenger demand? How accurate are these forecast methods?

2. TIME-SERIES DATA FOR TESTING FORECAST MODELS

The monthly data on passenger movements in the Mediterranean area from January 2013 to December 2018 are shown in table 1. To test the accuracy of the forecast models, we forecast passenger movement for January 2018 to December 2018 and compared the forecasts with actual values. Based on the accuracy analysis, we then choose the more accurate model for forecasting of cruise passenger demand.

Table 1. Monthly passenger movement in the Mediterranean region

Year	Month	Pax	Year	Month	Pax	Year	Month	Pax
2013	1	493,458	2015	1	614,385	2017	1	585,842
2013	2	427,829	2015	2	543,428	2017	2	522,749
2013	3	902,176	2015	3	743,948	2017	3	740,719
2013	4	2,105,291	2015	4	2,049,595	2017	4	2,308,613
2013	5	3,055,410	2015	5	2,979,908	2017	5	2,905,156
2013	6	2,989,328	2015	6	2,971,605	2017	6	2,763,468
2013	7	3,216,469	2015	7	3,281,594	2017	7	3,126,904
2013	8	3,466,197	2015	8	3,515,396	2017	8	3,201,749
2013	9	3,389,720	2015	9	3,499,428	2017	9	3,351,555
2013	10	3,663,072	2015	10	3,631,925	2017	10	3,644,332
2013	11	1,777,694	2015	11	1,785,280	2017	11	1,799,593
2013	12	704,729	2015	12	656,377	2018	12	964,893
2014	1	664,074	2016	1	618,681	2018	1	760,001
2014	2	512,506	2016	2	599,426	2018	2	676,502
2014	3	754,205	2016	3	1,002,070	2018	3	962,240
2014	4	2,210,709	2016	4	2,198,321	2018	4	2,743,717
2014	5	2,611,372	2016	5	3,018,321	2018	5	3,047,518
2014	6	2,753,546	2016	6	2,959,161	2018	6	2,950,601
2014	7	2,889,153	2016	7	3,492,826	2018	7	3,312,071
2014	8	3,168,154	2016	8	3,545,682	2018	8	3,251,336
2014	9	3,264,443	2016	9	3,570,017	2018	9	3,475,831
2014	10	3,437,962	2016	10	3,804,591	2018	10	3,893,959
2014	11	1,687,949	2016	11	1,810,276	2018	11	2,009,079
2014	12	699,886	2016	12	826,326	2018	12	956,581

3. SARIMA FORECAST MODEL

The forecasting models currently used for traffic forecasting can be distinguished into four groups: parametric regression models, nonparametric regression models, neural networks, and heuristics (Chrobok, 2005). Parametric regression models, also called auto-regressive integrated moving averages (ARIMA) method and its special cases of algorithms, like exponential smoothing or moving averages use time-series data to forecast values. Parametric regression models often provide useful forecasts, especially when dealing with a small number of variables, and a significant amount of reliable and valid data, where changes are expected to be large and predictable.

Cruise passenger demand forecast has become an essential issue for port decision-makers, as it has an important role in the development of the competitive position of port and region and their effects on the economy. Activities of ports and regions are closely related to changes in the global economy. Such forecasts are mainly of interest to terminal operators and port authorities since operational decisions and services are provided depending on passenger traffic.

The most commonly-used approach in time-series forecasting is the ARIMA model, which we use to forecast passenger flows. This model is suggested because it is known for its simplicity and ability to deal with time series and characterize an unknown system with few data points. The recorded data of passenger volume at a port is a time series, so ARIMA is appropriate for predicting future passenger movement. The basic idea of a univariate time-series model is that the value of variable *Yt* can be considered to be a combination of its own history (autoregressive—AR) and random effect (moving averages—MA), which have taken place in the past. ARIMA can be used only with stationary time-series (it should have a constant mean, variance, and autocorrelation through time). A stationary time-series does not depend on the time at which the series is observed. Time series with trends or seasonality are not stationary, so trend and seasonality will affect the value of the series at different times. Therefore, the time series first needs to be differenced until it is stationary. Short-term forecast of traffic data can be modelled based on stationary time-series (Shu, Shu, Nguyen, Lu, & Huang, 2014). The parameters used in ARIMA are: *p*, *d*, *q*, which refer to the autoregressive, integrated, and moving average parts of the data set, respectively. Parameter *p* is the number of lags in the differenced series appearing in the forecasting equation, called the autoregressive parameter (trend auto-regression order). The value of *p* is 0 if there is no relationship between adjacent observations; when the value is 1, there is a relationship between observations at lag 1. Parameter *d* is the difference levels to make a time series stationary, called integrated parameter (trend difference order), and *q* is the number of the lags in the forecast errors, called moving-average parameter (trend moving average order). ARIMA is advantageous because it only requires that the data of the interested variable be a time series. Moreover, it usually outperforms the more sophisticated structural models in providing robust short-term forecasts. The model is expressed as:

$$ARIMA(p,d,q) \tag{1}$$

where *p* is the parameter of *AR(p)*, *d* is the parameter of *I(d)*, and *q* is the parameter of *MA(q)*. For time series that show strong seasonal patterns and trend better stationery can be achieved with SARIMA (seasonal ARIMA). To deal with seasonality in the time series, ARIMA is extended to SARIMA (*p*, *d*, *q*) (*P*, *D*, *Q*) *s* model, which is expressed in terms of the lag operator. The capital letters *P*, *D*, *Q* refer to the seasonal components, respectively, and the *s* denotes the seasonal period (Box & Jenkins, 1976). Parameter *p* is the non-seasonal order of the autoregressive part, *q* is the non-seasonal order of the moving average part, and d is the order of regular differencing. Parameter *P* is seasonal autoregressive order, *D* is seasonal difference order, *Q* is seasonal moving average order, and *s* is the number for time steps for a single seasonal period. The SARIMA model is expressed as:

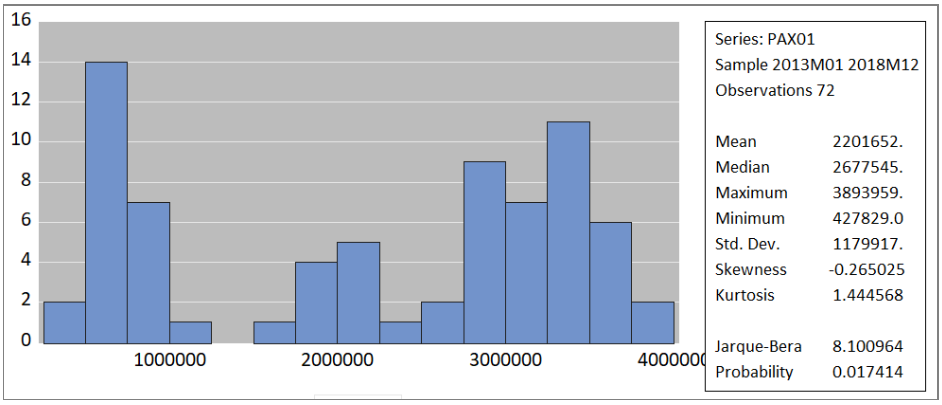
$$SARIMA(p,d,q)(P,D,Q)m \tag{2}$$

where parameter *s* influences the *P*, *D*, and *Q* parameters. For example, an *s* of 12 for monthly data suggests a yearly seasonal cycle. Many studies on time-series analysis and forecasting go deeper into these methods and their parameters, for instance. SARIMA models are used in forecasting when the data exhibit a seasonal trend. X-12 ARIMA method of seasonal adjustment can be used for removing the seasonal component from the time series and the multiplicative decomposition of the log data for seasonally adjusted time-series data and seasonal factors. Removing the seasonal component helps focus on other components and allows better analysis. For the forecast, we used SARIMA:

$$SARIMA(1,0,1)(1,1,0)_{12} \tag{3}$$

The Jarque-Bera normality test was used to conduct a single or joint hypothesis test for the model parameters.

Table 2. Jarque-Bera normality test



In the normality test, the Jarque-Bera probability is not greater than 0.05, so the model is not normally distributed. The value of skewness should be zero, but it is very low in our case, meaning that the data are fairly symmetrical. The kurtosis of any univariate normal distribution is 3, but in our case is 1.44 meaning that distribution is short and the tails are thinner than that of normal distribution.

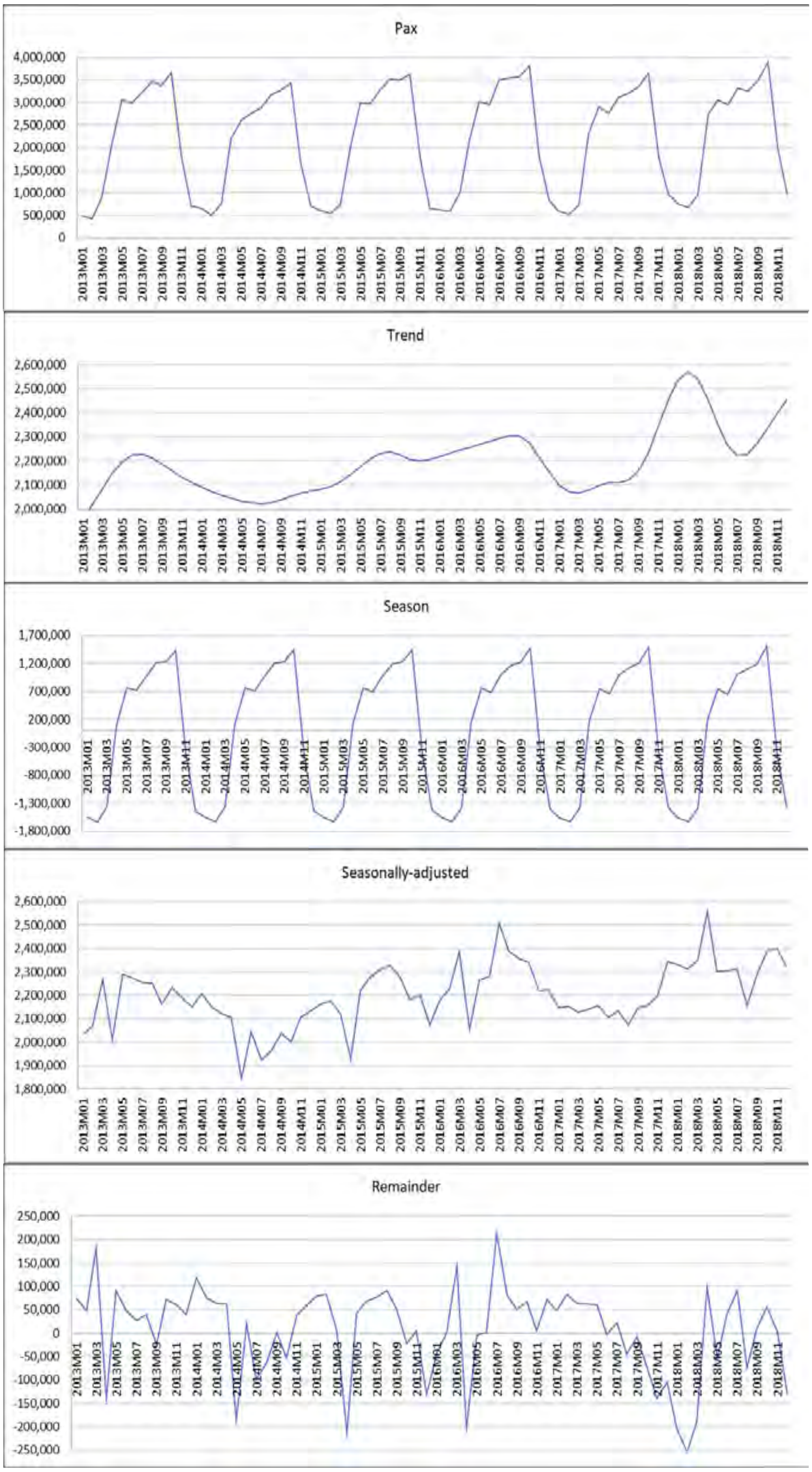


Figure 1. X-12 ARIMA decomposition of time-series data for passenger movement in the Mediterranean area

To forecast values with the seasonal component we didn't consider usual seasonal fluctuations, typical trading day effects and holidays. However, it needs to be noticed that cruise traffic seasonality is also related to weather-related factors associated with the off-season. It follows that we considered just seasonal fluctuations within the movement of the time series, therefore we used a SARIMA model which deals with seasonality in the time series.

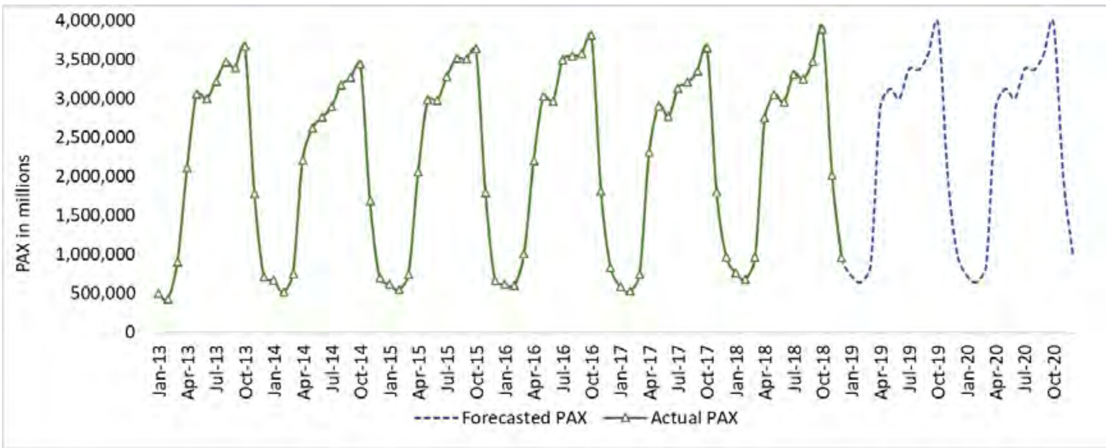


Figure 2. Graph of SARIMA forecasted values and actual values

4. STL FORECAST MODEL

The second method we use is the STL, which was developed by Cleveland, McRae, and Terpenning. The key to the STL approach is the LOESS smoothing (), which decomposes the time series into trend, seasonal, and remainder components.

$$Y_t = f(S_t, T_t, E_t) \tag{4}$$

where Y_t presents data at period t, S_t is the seasonal component at period t, T_t is the trend component at period t, and E_t is the remainder or irregular/error component at period t. The model in our case is given by:

$$Y_t = f(1,1,1) \tag{5}$$

Decomposition of time-series data helps to better understand the time series and improve forecasts. To perform the STL decomposition (figure 2), the seasonality of the data should be known, which is 12-monthly with a pattern reoccurring every year, in our study. To forecast a decomposed time series, it needs to be forecasted the seasonal and seasonally-adjusted components separately. It is usually assumed that the seasonal component is unchanging, so it is forecast by simply taking the last year of the estimated component.

In this model are considered just seasonal fluctuations within the movement of the time series.

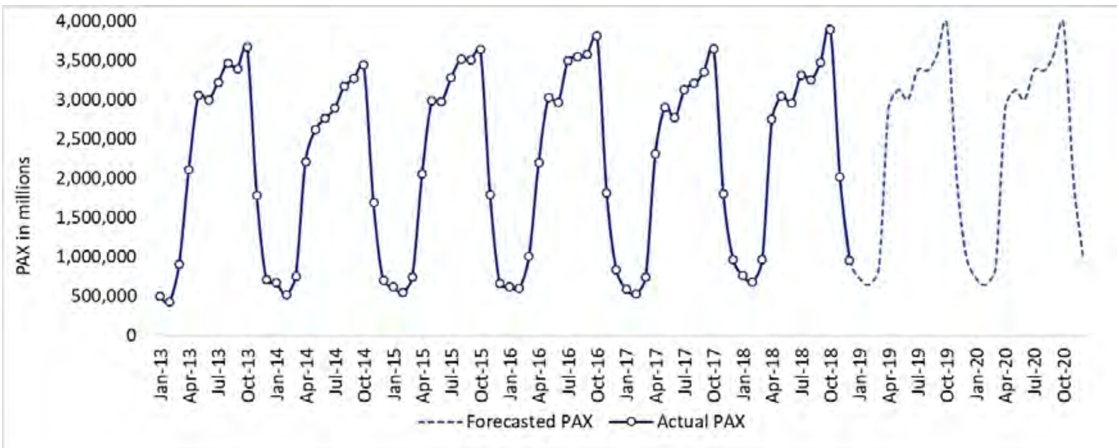


Figure 3. Graph of STL forecasted values and actual values

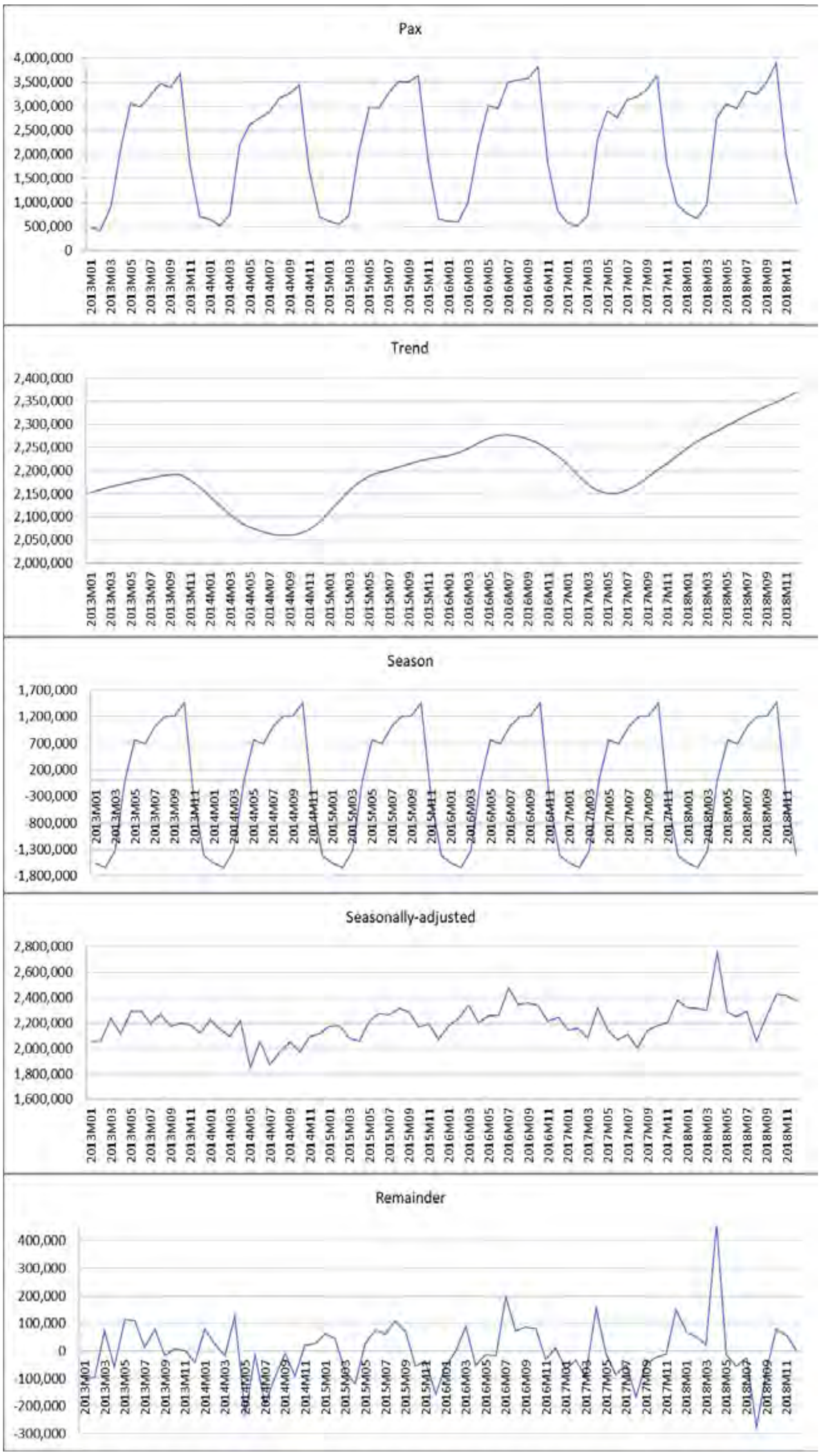


Figure 4. STL decomposition of time-series data for passenger movement in the Mediterranean area

The top plot in figure 4 is the raw data for passenger movement. The seasonal component is the yearly variation that occurs with monthly periodicity. Once the seasonal and trend components are fit, they are subtracted from the raw data to yield the remainder. After removing trend and seasonality from the original data set, the remaining presumed random values are an error.

5. ACCURACY ANALYSIS OF FORECAST MODELS

This paper aims to find which of the two presented forecast models is more accurate. We will now discuss the different measures for comparing the two. Since there is no universally accepted measure of accuracy that can be applied to evaluate forecasting, several accuracy measures were used for both methods. We considered three criteria for measuring accuracy—mean absolute error (MAE), mean absolute percentage error (MAPE), and root mean squared error (RMSE). While testing the forecast accuracy, we have to assume that a forecast will be as accurate as it was the past and that its future accuracy can be guaranteed. Let F_t be the forecast value and Y_t be the actual observation at time t. Then, the forecast error at time t is defined as:

$$\varepsilon_t = Y_t - F_t \tag{4}$$

In this case, F_t is called the one-step forecast and ε_t is called the one-step forecast error. Usually, we assess error from not one ε but from n values. The simplest measure of forecast accuracy is called MAE (Cleveland, Cleveland, McRae, & Terpenning, 1990):

$$MAE = \frac{1}{n}\sum_{t=1}^{n}\left|\varepsilon_t\right| = \frac{\sum_{t=1}^{n}\left|Y_t - F_t\right|}{n} \tag{5}$$

MAE provides the absolute value of the difference between the forecasted value and the actual value. It indicates the size of an error that can be expected from the forecast on average. We can also use relative or percentage error (PE) measurements.

$$PE = \left(\frac{Y_t - F_t}{Y_t}\right)\cdot 100 \tag{6}$$

Sometimes, the relative error is not always obvious from MAE, so we find MAE in percentage terms with MAPE, which allows the comparison of forecasts of different series in different scales.

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|PE_t\right| = \frac{100\cdot\sum_{t=1}^{n}\left|\frac{Y_t - F_t}{Y_t}\right|}{n} \tag{7}$$

Since both the MAE and MAPE methods are based on mean error, they could understate the impact of large, but infrequent, errors. If we focus too much on the mean, we will be caught off guard by the rare, large errors. To adjust for such errors, we calculate RMSE. We can also compare RMSE and MAE to determine whether the forecast contains rare, large errors. The larger the difference between RMSE and MAE, the more inconsistent the error size. RMSE is given by (Chai & Draxler, 2014) as:

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}\left(Y_t - F_t\right)^2}{n}} \tag{8}$$

Table 3. Accuracy analysis of forecasting models

Forecasting model	Accuracy measure 2018		
	MAE	MAPE	RMSE
SARIMA	217,430	0.105	266,937
STL	62,450	0.032	113,325

The comparative results of the two models indicate that STL is more accurate since it has a lower value on all three performance measures. The MAPE values demonstrate that STL is more accurate with

3.2% error. With a plot of the actual and predicted values generated using SARIMA and STL, we get a clearer view of the comparison and error. To estimate SARIMA forecast model we checked several ARMA models. The best fitted ARMA model (2,1)(1,1) is shown in Figure 5 coloured red, with the other forecasts in grey (70 models).

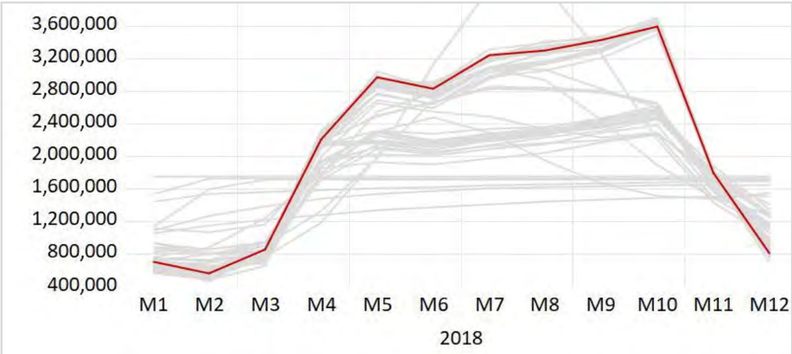


Figure 5. Forecast Comparison Graph of ARMA models

Figure 6 shows that STL generates more accurate values than SARIMA, as the curve is more fitted to the actual values.

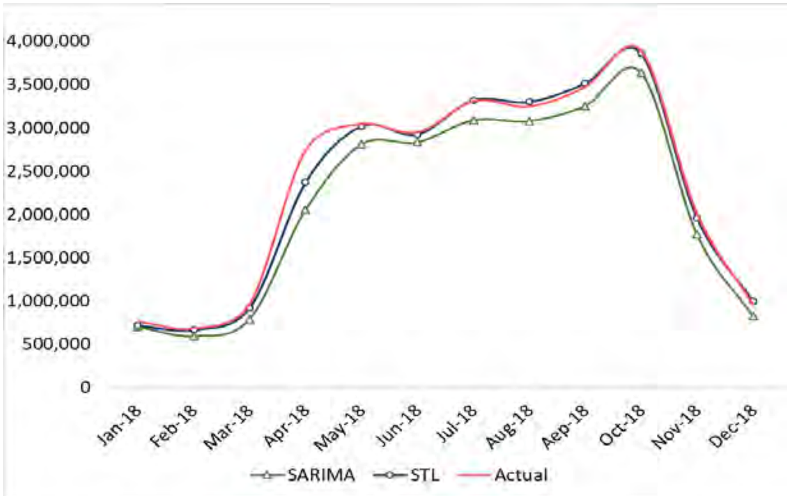


Figure 6. Accuracy graph of SARIMA and STL forecast models

Using STL, we forecasted that passenger movement in 2018 would reach 27.6 million Pax. In comparison, SARIMA model forecasted that passenger movement in 2018 would reach 25.4 million Pax. However, MedCruise Association reported that the actual number of passenger movement at MedCruise ports in 2018 was 28.04 million, which was a record for it (MedCruise, 2019) With the comparative results of forecasting accuracy of the two models, we forecasted passenger movement for the next two years (figure 7).

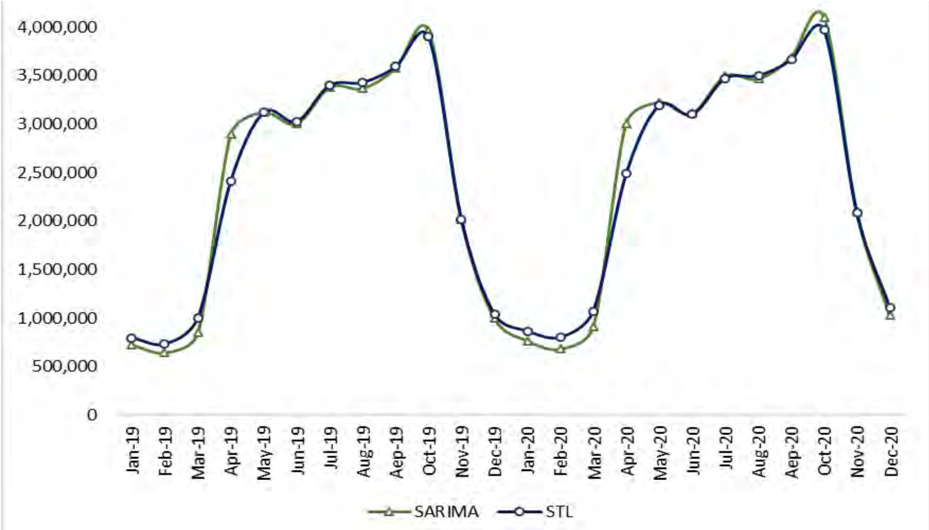


Figure 7. Graph of comparison between SARIMA and STL forecasted values for 2019 and 2020

Figure 7 shows a comparison between the STL and SARIMA forecasted data for 2019 and 2020. STL yields higher values than SARIMA. Considering the accuracy of both, STL should yield more accurate values since it has a lower error than SARIMA.

Table 4. Forecasted values of Pax and comparison between SARIMA and STL forecasted values

Year	Month	Pax (SARIMA)	Pax (STL)	Year	Month	Pax (SARIMA)	Pax (STL)
2019	1	725,072	794,400	2020	1	767,992	865,252
2019	2	644,991	730,959	2020	2	683,326	801,811
2019	3	850,704	1,001,989	2020	3	911,245	1,072,841
2019	4	2,896,496	2,416,365	2020	4	3,006,988	2,487,217
2019	5	3,123,153	3,121,892	2020	5	3,225,777	3,192,744
2019	6	3,004,582	3,028,073	2020	6	3,110,287	3,098,925
2019	7	3,381,836	3,401,661	2020	7	3,497,471	3,472,513
2019	8	3,369,245	3,431,656	2020	8	3,466,385	3,502,508
2019	9	3,575,207	3,592,627	2020	9	3,687,913	3,663,479
2019	10	3,963,389	3,903,702	2020	10	4,103,485	3,974,554
2019	11	2,013,571	2,016,582	2020	11	2,096,099	2,087,434
2019	12	999,615	1,039,834	2020	12	1,025,407	1,110,686
Σ	12	28,547,861	28,479,740	Σ	12	29,582,375	29,329,964

Table 4 shows that passenger movement in 2020 will exceed 29 million Pax and, in the most optimistic scenario, it could exceed 30 million Pax. Here, we need to consider the accuracy of the two models where STL has 3.2% error. So, the actual forecast of passenger movement for 2020 is between 28,394,195 to 30,265,733 million Pax, considering 3.2% rate of error. Leading cruise ports and the most popular destinations in the Mediterranean will witness an increase in cruise passengers, consequently, leading to more challenges for cruise ports. Ports need to respond to this increasing demand by expanding port capacity and developing infrastructure.

6. CONCLUSION

One of the important things in port infrastructure investment decisions and managing passenger traffic flow is to know how passenger demand will change in the short term. A reliable forecast model to predict passenger demand is essential for terminal operators and traffic planners to make decisions on port infrastructure. There are many forecast methods with different accuracy levels. In this paper, we compare two forecast methods—STL and SARIMA—to forecast passenger volume. To compare model accuracy, we forecasted the time-series passenger movement data for January 2013–December 2018 and compared the predicted values with actual values. The analysis led to important conclusions. First, it was noticed that STL yields more accurate results with less error, so we conclude that it is more reliable for short-term forecasting than SARIMA. We need to stress out, that typical calendar effects and weather-related factors within the movement of the analyzed time series were not considered. Second, by analyzing seasonality and fluctuation in cruise activity in the Mediterranean region, it was observed that traffic is concentrated in the summer months, with a peak in October. Third, forecasting passenger movement is important for port authorities and terminal operators as it affects the planning of terminal infrastructure, as well as traffic flow management and operational decisions at cruise terminals. Forecasted values of passenger movement provide port authorities with a good perspective of the region where the port is situated. In this analysis, we forecast passenger movements in 2019 and 2020 and notice a positive outlook for ports in the Mediterranean region. It can be concluded that the seasonal component in forecasted values is unchanged. The results of this study could be helpful for predicting short-term variations in passenger demand at cruise ports.

REFERENCES

[1] Box, G., & Jenkins, G. (1976). The Box-Jenkins Method.

[2] Chai, T., & Draxler, R. R. (2014). Root mean square error (RMSE) or mean absolute error (MAE)? – Arguments against avoiding RMSE in the literature. Geoscientific Model Development.

[3] Chrobok, R. (2005). Theory and Application of Advanced Traffic Forecast Methods. Universitat Duisburg-Essen. Retrieved from https://duepublico2.uni-due.de/servlets/MCRFileNodeServlet/duepublico_derivate_00005656/Chrobokdiss.pdf (15.5.2019)

[4] Cleveland, R. B., Cleveland, W. S., McRae, J. E., & Terpenning, I. (1990). STL: A Seasonal-Trend Decomposition Procedure Based on Loess. Journal of Official Statistics, Vol. 6 No. 1.

[5] Dokumentov, A., & Hyndman, R. J. (2015). STR: A Seasonal-Trend Decomposition Procedure Based on Regression. Working paper.

[6] MedCruise. (2019). MedCruise Statistics Report 2018. Retrieved from http://www.medcruise.com/ (Accessed on 4.7.2019)

[7] Montgomery, D. C., & Runger, R. C. (2002). Applied Statistics and Probability for Engineers. Third Edition.

[8] Peng, W.-Y., & Chu, C.-W. (2009). A comparison of univariate methods for forecasting container throughput volumes. Mathematical and Computer Modelling, Vol. 50(Issues 7-8).

[9] Schulze, P. M., & Prinz, A. (2009). Forecasting container transshipment in Germany. Applied Economics.

[10] Shu, M.-H., Shu, B.-M., Nguyen, T.-L., Lu, C., & Huang, J.-C. (2014). Forecasting Cargo Throughput with Modified Seasonal ARIMA Models. Retrieved from http://www.wseas.org/multimedia/journals/mathematics/2014/a065706-309.pdf (6.12.2018)

[11] Washington, S. P., Karlaftis, M. G., & Mannering, F. L. (2003). Statistical and Econometric Methods for Transportation Data Analysis.

INTELLIGENT TRANSPORTATION SYSTEMS IN CROATIAN SMART CITIES

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Summary

Cities across the world are trying to develop into so called Smart Cities. Generally, one of the main goals of Smart Cities is an efficient and sustainable transportation. Decreasing traffic congestion, improving mobility and environment preservation are some of the biggest transportation challenges. Non-efficient city transportation, especially when significant congestions occur, impacts nearly all aspects of city functions and its development. To overcome these challenges many city planners are looking to smart public transport solutions, including development and introducing of new transport means, combining different existing means of transport or altering the transport organization using the existing means and infrastructure. More than 40 out of a total of 128 cities in Republic of Croatia use smart transportation initiatives to optimize their public transportation routes, create safer roads, reduce infrastructure costs and traffic congestion. This paper presents an analysis of intelligent transport solutions introduced in Smart Cities across the Republic of Croatia. The main goal is to analyze the efficiency of the smart mobility initiatives and to investigate the importance of information and communication technology in supporting smart mobility actions, influencing on the citizens' quality of life.

Keywords: Smart Cities, Smart Mobility, Information and Communication technology, Republic of Croatia

1. INTRODUCTION

Nowadays, half of humanity or approximately 3.5 billion people live in cities, and in future it is expected that this number will continue to increase [1]. According to data taken form Smart Cities Council, approximately 55% of the world's population lives in cities. The United Nation estimates that in year 2050 the urban population will increase to 6.3 billion inhabitants. Nowadays, in Republic of Croatia about 60% of the population lives in cities across the country and it is expected that 63% of the population will be living in cities by year 2025 [17]. Although cities occupy just 1% of the Earth's land, they account for 75% of energy consumption and 80% of CO_2 emission [19].

This growth has had a profound impact on the global economy, as approximately 70% of the world economic activity now occurs in urban areas [18]. These trends make it clear that urban areas are the central economic, political, and social hubs of the 21st century. According to aforementioned, cities play a key role in sustainable development so they must be managed in ways that support economic, social and environmental sustainability. The above mentioned could not be fulfilled without use of novel information and communication technologies (ICT). ICT are necessary for transforming traditional city to smart one and to enable the efficient use of infrastructure, services and administrative systems in order to achieve sustainability.

The Republic of Croatia as a member of the European Union puts a lot of effort to make its cities smart. The Republic of Croatia has less than 4 billion inhabitants overall and 17 cities that have the status of a large city (more than 35,000 inhabitants). Most of these cities have the status of a Smart City. Except large cities, there are more than 40 (out of 128 cities in total) that use intelligent solutions for a better management and a better living standard.

In Croatia the development of Smart City infrastructure is at an initial level, but is progressing rather fast. Approximately 50% of Croatian cities have already started the process of implementing one or more smart solution projects [1]. The objective of this paper is to analyze the current situation regarding intelligent transport solutions (Smart mobility) introduced in Croatian Smart Cities.

2. THE SMART CITY CONCEPT

Despite there is some kind of consensus in broad literature that the label "Smart City" represents innovation in city management, it's services and infrastructure, a common definition of this term has not yet been stated. There is a wide variety of definitions of what a Smart City could be.

Today there are several various definitions of the Smart City suggested by different organizations, specialists and scientists from different scientific fields. Hereafter are presented some definitions and explanations of the term as perceived by different authors and institutions:

- A Smart City uses information and communications technology (ICT) to enhance livability, workability, and sustainability [19].
- A Smart City is a city seeking to address public issues via ICT-based solutions on the basis of a multi-stakeholder, municipally based partnership [8].
- According to the Manchester Digital Development Agency, Smart City means Smart Citizens – where citizens have all the information they need to make informed choices about their lifestyle, work and travel options.
- IBM defines a smart city as "one that makes optimal use of all the interconnected information available today to better understand and control its operations and optimize the use of limited resources.
- The British Standards Institute (BSI) defines the term as "the effective integration of physical, digital and human systems in the built environment to deliver sustainable, prosperous and inclusive future for its citizens".
- The UK Department for Business, Innovation and Skills (BIS) considers smart cities a process rather than a static outcome, in which increased citizen engagement, hard infrastructure, social capital and digital technologies make cities more livable, resilient and better able to respond to challenges.
- According to Mark Deakin and Husam Al Waer Smart City is a city that utilizes ICT to meet the demands of its citizens, and that community involvement in the processes is a necessity for a Smart City. From the definition given by Husam Al Waer and Mark Deakin in their research publication

"From Intelligent to Smart Cities," the factors that contribute to a city being classified as smart are: the application of a wide variety of digital and electronic technologies to the city and its communities, the application of ICT to uplift life and the working environments in the region, the embedding of such ICT within government systems, the territorialisation of practices that bring the people and ICT together in order to innovate and enhance the knowledge that they offer.

- The use of ICT makes the critical infrastructure components and services of a city – which include city administration, education, healthcare, public safety, real estate, transportation, and utilities – more intelligent, interconnected, and efficient [45].
- A city is smart when investments in human and social capital and traditional and modern communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance [5].
- A smart city is where the ICT strengthens freedom of speech and the accessibility to public information and services [2].

From above examples it can be deducted that most definitions are technologically oriented. It may be assumed that the definition of the Smart City will evolve as different aspects of technology will be developed.

Regarding the Smart City concept there are numerous resources but they all equally define the Smart City concept. Smart City concept contains several axis of a city that relates to (Figure 1) [11,12]:

- Smart Economy – means the use of ICT solution in a business and entrepreneurship sectors
- Smart People – means the use of ICT tools for access to education, to make decision based on appropriate data and to create new products
- Smart Governance – means the use of ICT tools for example web platforms or mobile applications to enable data transparency for different stakeholders.
- Smart Mobility – means ICT supported transport with real-time data
- Smart Environment – means ICT enabled energy grids with monitoring and pollution control
- Smart Living – means ICT- enabled lifestyles which reduce energy and water consumptions.

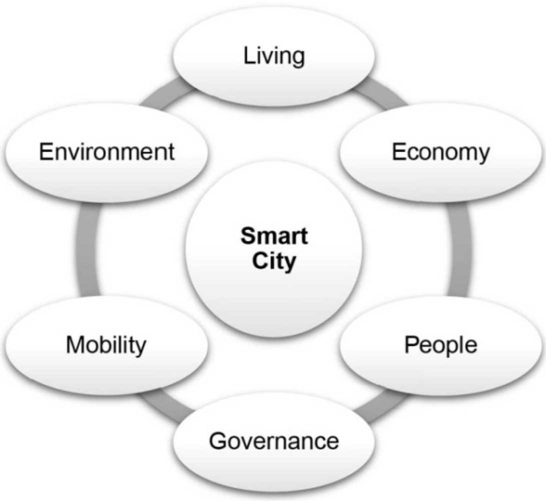

Figure 1 The Smart City concept

Source: Authors, according to [11, 12]

Furthermore, all aforementioned axis of smart city integrates four different networks: Internet of Things (IoT), Internet of People (IoP), Internet of Services (IoS) and Internet of Data (IoD) (Figure 2).

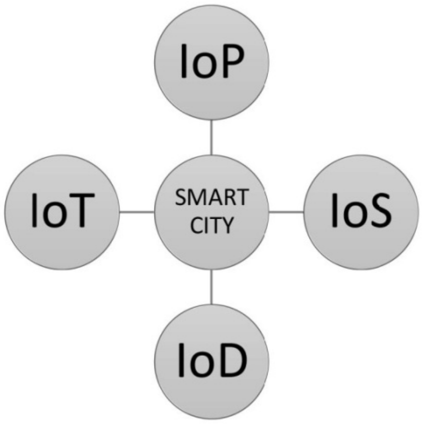

Figure 2 Internet networks in the Smart City

Source: Authors

Internet of Things represents the technology where data are automatically transferred over network without any human interference. Internet of Things refers to different devices, mobile and static sensors and usefully resolves many problems in a city. City collect many real-time data obtained from road sensors, mobile phones, street cameras, drones and other sources, and for example, if there is a car accident or traffic congestion with the help of IoT other car drivers can be directed to another road that is less congested.

Internet of People (IoP) represents the mapping of social individuals and their interactions with smart devices to the internet [42]. IoP includes collection, modelling, and ubiquitous intelligence for a wide range of applications which are crowd sourced, internet-based personal information.

Internet of Service (IoS) is a next-generation blockchain technology that provides the network infrastructure to support a service-oriented ecosystem [20]. IoS includes cloud-based solutions, processes, tools and operations.

Internet of Data (IoD) represents linking of open data and data analytics. The aim of IoD is to collect useful information, combine them and deliver them to end users through internet. All aforementioned internets are necessary for providing data transfer and useful information between citizens of a certain city.

3. SMART MOBILITY AS KEY ASPECT OF A SMART CITY

The Smart Mobility integrates citizens and transportation through innovative technologies to improve their mobility [21]. The Smart Mobility as a concept consist of few components which include infrastructure, technology, information and services. Jekkel, H., defined the four components of Smart Mobility [16]:

- Vehicle technology: the basis are new types of vehicles powered by efficient alternative fuels (usually electricity), autonomous, safe and equipped with vehicle dynamics control and car systems assisting drivers.
- Intelligent Transport Systems (ITS): the improved ITS solutions brought a new level of interconnected cars, cooperative adaptive cruise controls, and intelligent traffic management
- Data: the real time data plays significant role in Smart Mobility and includes passengers' information, personalized travel assistance, logistics planning, IT systems matching supply and demand for mobility, Big data, IOT. [3].
- New mobility services: optimal utilization of existing vehicle and truck capacity, carsharing, new biking systems, integration of transport modes, using smartphones for facilitating mobility and ticketing, on-demand ride services, use of individual cars as public transport.

Furthermore, Smart Mobility is one of the key factors enabling sustainability in cities, since the urban transport generates negative impact on environment in cities and also affects the economic and social components of living in the city. The goals of Smart Mobility can be summarized as follows [22]:

- reduce environmental impact,
- improve planning and efficiency of public transport means,
- optimize parking spaces and their management,
- reduce congestions and citizens frustration,
- prioritize the citizens in the mobility,
- improve living quality for the citizens.

The European citizens living in urban areas will count 80% up to year 2050 [9]. E.g., in the Europe 70% of journeys are made by car (private car, taxi or car-sharing) making the road transport a dominant mode. 55% of public transport rides are made by buses [10]. In European cities, over 90% of citizens use a smartphone more than any other device. 57% of Croatian citizens point out the mobile phone as the device they would most likely pay with while 22% citizens already use some variation of mobile payment method [27]. Smartphones and mobile payment methods are very useful to facilitate the Smart Mobility.

Hereafter are presented some Europe cities as good examples in implementing a Smart Mobility concept. The Netherlands is recognized as one of the leading countries in the future of Smart Mobility. The capital Amsterdam is committed to sustainability and citizen-focused modes of travel. Amsterdam has high reliance on bicycles as a key mode of transport (32%) and also on walking (29%). Considering all modes of citizens' transport in Amsterdam, the public transport ratio is 17% while the private mode of transport using cars ratio is 20%. The example of Amsterdam shows how cycling can take prominent role in the future of urban mobility [23].

The City of Helsinki is one of the first cities which implemented the Smart Mobility concept which continuously develops. Their aim is that all citizens do not have a need to own a private car by year 2025 [24]. Furthermore, in Deloitte Study on City Mobility Index, Helsinki is rated as a city committed to innovations such as a self-driving public bus and it is marked as a leader in Future of Mobility concepts such as MaaS (integration of various forms of transport services into a single mobility service accessible on demand). To meet a customer's request, a MaaS operator facilitates a diverse menu of transport options, being public transport, vehicle sharing (ride, car or bike), taxi or car rental/lease (or a combination). In addition, Helsinki has the following transport model ratios of use: 30% of public transport, 21% walking, 8% cycling and 39% private transport by car [25].

Vienna, the capital of Austria made a significant progress in Smart Mobility. Recently the first autonomous or self-driving bus was put into operation, and the first autonomous air taxi in Austria should be ready for series production by year 2020 [26].

In addition to the increasing demand for urban mobility, there are other factors which emphasize the importance of implementation of Smart Mobility solutions: changed travel habits, rise of collaborative mobility, demand for services to increase convenience, speed and predictability and evolving customer expectations towards customization [28].

4. SMART MOBILITY IN THE REPUBLIC OF CROATIA

Smart Mobility concept is still in developing phase in Croatia. The Smart Mobility solutions are concentrated in the capital city of Zagreb and main region cities. There are also several small cities which are aware of benefits of Smart Mobility.

The Department of Urban Transport at the Faculty of Transport and Traffic Sciences has conducted a research regarding the current knowledge and implementation of Smart Mobility and Smart City concepts in

Croatian cities. In cooperation with the Association of Cities, research has been conducted on 23% of all cities in the country (altogether 128 cities). The research has showed the following results [4]:

- 32% of participated cities are involved in the implementation of the Smart City concept; 64% are planning to start;
- The key components of Smart Mobility are ICT technologies (86,2%), smart public transport (65,5%) and smart parking (58,6%);
- The implemented Smart City solutions are: Air quality control (33%), traffic control (22%) and smart parking (11%);
- Smart mobility solutions that the observed cities will be implementing in future are: ICT technologies (60, 7%), smart parking (50,0%), traffic control (39,3%) and smart public transport (32,1%);
- 51,7% of cities are ready to allocate certain financial resources for Smart City and Smart Mobility solutions.

Furthermore, the results showed that there is no systematic collection of data for the indicators of smart mobility level and that the existing data are not harmonized on the national level. For the purpose of measuring the level of mobility, efficiency or sustainability, it is necessary to standardize the collected data into a comprehensive index of indicators at the level of the Republic of Croatia, according to leading European and global trends [43].

The survey on carsharing in Croatia conducted on 183 persons resulted as follows [14]:

- 30,6% of respondents didn't know the meaning of carsharing;
- 50% of respondents who knew the meaning of carsharing used it very rarely;
- 68,3% of respondents showed the interest to use the carsharing in case of possibility.

Table 1 presents the implementation of the state-of-the-art of the Smart Mobility technologies in Croatia as follows: smart parking, smart bus station, e-Bike, e-Scooter, EV charging Stations, carsharing, park and ride, automated traffic management systems, smart travel information applications. To provide a comprehensive analysis the focus is placed on the capital of Croatia - Zagreb, and on the main regional centers Split, Rijeka, Osijek, Zadar, Pula and Dubrovnik.

Table 1 Smart Mobility solutions in Croatian cities

Smart Mobility Technologies	City						
	Zagreb	Rijeka	Split	Osijek	Zadar	Pula	Dubrovnik
Smart parking	X	X	√	X	X	X	√
Smart bus station	X	√	X	X	X	X	X
e-Bike	√	√	√	X	√	√	√
e-Scooter	√	√	√	X	√	√	√
EV charging station	√	√	√	√	√	√	√
Carsharing	√	√	√	√	√	√	√
Park and Ride	√	X	X	X	X	X	X
Automated traffic management system	X	√	X	X	X	X	X
Travel info apps	√	√	√	√	√	√	√

Source: Authors

The capital of Croatia, Zagreb, is the only city in Croatia with implemented Park and Ride system. Located near the main railway station Park and Ride offers citizens the possibility to combine the use of parking and city transportation [29]. Via tickets citizens are able to park for unlimited time and continue their transport using bus or tram. Furthermore, Zagreb has a well-developed network of EV charging stations which are mainly available in public garages and shopping malls. Zagreb is also intensively developing e-Bike services since cycling is becoming continuously more popular in Zagreb [30]. E.g. the e-Bike Zagreb company offers simple online bike booking in range of hour to weekend booking [30]. Zagreb has introduced carsharing e.g. via Spin City Application. After the registration and payment, a user is able to unlock the car using the application and use it. All cars are eco-friendly (currently 30 cars) which are available at all times, and users have may freely use the parking places around the city [31].

The City of Rijeka is one of the most prominent city in Croatia in terms of Smart City concept with a clear strategy for development of Smart Mobility. In 2015, the City of Rijeka established the ''Smart RI'' center which acts as a cluster manager linking business entities and research institutions to develop projects for smart cities. Partners have conducted six researches and developed two projects in Smart Mobility field from which: SmartCity.Trans and SmartCity.Surinmo. The SmartCity.Trans (Traffic Management and Internet of Things) is aimed at advanced analytic solution for increased security, advanced algorithms for detection of traffic anomalies, incidents and dangerous situations. The SmartCity.Surinmo aims at development of platform for connected, energy efficient and shared urban mobility. In detail, through the project it will be developed the e-Roaming platform for e-vehicle charging, carsharing, digitalized parking and public transport. Furthermore, the system of E-signs will provide safety and information as well as the redirection of transport. The E-crossing is a part of Surinmo focused on integration with Smart City Platform [32].

First smart bus stations in Croatia are implemented in Rijeka in 2017. The implemented Automated Traffic Management System in Rijeka aims to optimally manage traffic under the given conditions. Modern traffic management technology allows the management of light traffic signaling, depending on the prevailing traffic loads in the traffic network [33]. The system is modular and can be easily adapted to new traffic conditions. Rijeka still lacks of Park and Ride system although there has been the initiative to organize it. Smart Parking is still not implemented in Rijeka.

The City of Split is one of the first cities in Croatia which implemented the Smart Parking. The citizens use Smart Split parking application which is considered as one of the best applications in Croatia of that kind. The system uses sensors to detect whether the parking space is free or busy, and the application user sees the current situation on his/her mobile phone. The parking availability is visible in the form of a pin on the map, which contains numerical information about free parking spaces. The application also offers the user the ability to navigate to the nearest free parking space. In application, free parking spaces for persons with disabilities are emphasized. The system enables reduced crowds, better driving experience and eco-effect in the form of lower polluting emissions [34].

The City of Osijek has provided EV charging stations, carsharing and smart travel information applications for citizens. Other systems and technologies are in process of development through various EU projects in which Osijek is especially active.

The City of Zadar and the City of Pula are continuously developing their e-Bike and e-Scooter capacities mainly in order to improve their touristic offer. The Tourism Office Pula provides e-Bikes at one spot. To use this service tourists or citizens must show one personal document and after data acquisition they may rent an e-Bike [35]. Behind various companies Zadar provides e-Bike through Nextbike Smart Bike Renting System. Once registered with bike sharing system it's possible to rent bikes at different locations. The rent and return of the bikes are possible by phone, online, via smartphone application or at one of rental terminals [36].

The City of Dubrovnik is becoming the smartest city in Croatia in the sector of Smart parking. Although Smart parking already exists few years, Dubrovnik is investing in Smart parking by development of sensor network and technology introducing 1.900 new sensors based on IoT network [37]. The system already provides the similar service as the city of Split, offering the information on parking space availability. Dubrovnik also has the first smart street in Croatia, developed in partnership with the telecommunication operator T-Com. The street has a multifunctional sensor network installed with public lighting, wireless high-speed Internet connection, cameras that monitor traffic violations, smart parking with contactless payments, and environmental conditions control.

5. FUTURE PERSPECTIVE OF SMART MOBILITY IN THE REPUBLIC OF CROATIA

The City of Rijeka, City of Split and City of Dubrovnik are the leading cities in Croatia using different Smart Mobility technologies and generally in Smart City concept. The Park and Ride, smart parking and smart bus stations are the technologies which cities lack the most. Other technologies vary from city to city. The analyzed cities are aware of importance of Smart Mobility technologies to improve the quality of transport service for citizens and to contribute to sustainability goals and thus are implementing strategies, plans as well as concrete projects.

E.g., the City of Zagreb prepared the smart city Strategy up to 2030 ''Zagreb Smart City'' in which one of the strategic goals is Sustainable Urban Mobility, including:

- integrated passenger transport on the basis of a unique modernized integrated transport system with mobile application and a non-contact card (actual mileage / cell payment).
- Passenger information system and travel planning and video surveillance system for public passenger transport.
- Introducing a system of free information on free capacities at parking lots (or free parking spaces), a navigation system for free street and off-street parking spaces, a system for the remote reservation of parking spaces (including electric vehicle charging stations).
- Continuous development of Park and Ride systems (residents who live on the boarders of the city or outside the city can freely park their vehicles on the tram turnaround and continue the route by public transport).
- System and application solution for cyclists (info about cycling trails, bike sharing, route planning and travel time, traffic, shipping, pollution, etc.).

The City of Osijek is currently developing electric carsharing system under the EU project ''I-SharE LIFE''. The aim of the project is to reduce the number of conventional vehicles in use, thus reducing the emission of pollutants. The City of Osijek started pilot activities to implement 8 electric cars with a special focus on the development of electric vehicle distribution models, the integration of IT solutions of shared electric vehicles and public transport operators, and related modelling of future services for different user groups [40].

ThCity of Rijeka adopted the Strategic plan "Rijeka Smart City 2019-2020" where Smart Mobility takes an important part. Some of the current and future project of Smart Mobility in Rijeka are: ECOMOBILITY – ecologic support to sustainable traffic management in coastal areas using intelligent systems (City of Rijeka), Sustainable urban Mobility plan (City of Rijeka), Smart traffic lights (Rijeka promet), Solar tricycle for waste collection (Rijeka promet), Strengthening the public transport system (Autotrolej) [13].

The City of Dubrovnik has adopted the strategy ''Smart City Dubrovnik 2020'' which aims at: Promoting the development and implementation of sustainable and urban transport; introducing e-vehicles and filling stations for the same in the city; encouraging the use of sustainable forms of transport, reducing CO_2 and toxic gas emissions; developing the integrated transport system (Airport and the suburban and interurban bus station with Port of Gruž) [7].

6. CONCLUSION

Nowadays half of Earth population lives in cities, so the cities have the key role in sustainable development in general. The Republic of Croatia as a member state of European Union is trying to transform the traditional cities' management to smart ones respecting the principles of sustainable development. Currently there are 40 Smart Cities in Croatia and some of them have developed solutions in the Smart Mobility domain. Smart Mobility is a key element of Smart City closely related to the Smart Environment and Smart Living. Without the Smart Mobility any city cannot be categorized as Smart. According to the conducted analysis in the cities across Croatia it can be concluded that Smart Mobility solutions are mostly concentrated in the capital city and capital cities of regions and that the concept of Smart Mobility is still in development phase. The City of Rijeka, City of Split and City of Dubrovnik are the leading cities in Croatia in Smart Mobility. The City of Rijeka is the only city in the Republic of Croatia which developed the Automated Traffic Management System for optimal traffic management while the City of Split and City of Dubrovnik are the only cities where the smart parking based of IoT network is implemented. The capital city, City of Zagreb is the only city with implemented Park and Ride System. This technology all other cities lack the most. The growth of transport solutions including ticket management, guidance systems, parking and traffic management could increase the demand in the smart city market. Changing travel habits, the rise of collaborative mobility, the demand for services to increase convenience, speed and predictability, as well as evolving customer expectations towards customization, will require more intelligent infrastructure able to cope with these demanding mobility requirements.

REFERENCES

[1] Al-Garby, A., Selak, G., Čičak, A.M., Glavičić, L.,Gošović, G.: The Smart City sector in Croatia, Zagreb, Flanders Investment & Trade Market Survey, 2017, pp.1 -15.

[2] Anthopoulos, L., Fitsilis, P.: From digital to ubiquitous cities: Defining a common architecture for urban development. In Proceedings of the 6th International Conference on Intelligent Environments (Kuala Lumpur, Malaysia, Jul 19-21), 2010.

[3] Beswick, S.: Smart cities in Europe - The future of urban mobility, Osborne &Clark, 2015.

[4] Brčić, D. et al.: The Role of Smart mobility in Smart Cities, 5th International Conference on Road and Rail Infrastructure, Zadar, Croatia, 2018, pp. 1601-1606,

[5] Caragliu, A., Del Bo, C., Nijkamp, P.: Smart cities in Europe. In Proceedings of the 3rd Central European Conference in Regional Science (Košice, Slovak Republic, Oct 7-9), 2009.

[6] Deakin, M., Al Waer, H.: From intelligent to smart cities, Intelligent Buildings International, 2011, Vol.3, No.3, pp.140-152.

[7] Deloitte: Strategija razvoja pametnog Grada Dubrovnika, 2015.

[8] Directorate General for Internal Policies Policy Department A: Economic And Scientific Policy, Mapping Smart Cities In The EU, Brussels, 2014.

[9] Directorate General for Mobility and Transport Directorate, Investment, Innovative & Sustainable Transport Unit B4: Sustainable & Intelligent Transport, European Urban Mobility, Policy Context, Brussels, 2017.

[10] European Automobile Manufacturers Association: Manifesto for Clean, Safe and Smart Mobility, Brussels, 2019.

[11] Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler, Milanoviü, N., Meijers, E.: Smart Cities: Ranking of European Medium-Sized Cities. Vienna, Austria: Centre of Regional Science (SRF), Vienna University of Technology, 2007.

[12] Giffinger, R., & Gudrun, H.: Smart cities ranking: An effective instrument for the positioning of cities? ACE: Architecture, City and Environment, 2010, Vol.4, No.12, pp.7-25,

[13] Grad Rijeka: Strateški plan; Rijeka Pametan grad za razdoblje 2019.-2020. godine, Rijeka, 2018.

[14] Hirnig, S., Šikić, L., Gržin, E.: Sustavi dijeljenja vožnji u funkciji smanjenja prometnih zagušenja uz zadržavanje dostignute razine mobilnosti stanovništva, Zbornik Veleučilišta u Rijeci, Vol. 5 (2017), No. 1, pp. 107-124.

[15] Indikatori mobilnosti u konceptu „Smart City", Zbornik okruglog stola, Fakultet prometnih znanosti, Zagreb, 2017, ISBN: 978-953-243-098-1.

[16] Jekkel, H.: Social Sustainability and Smart Mobility, Transportation Research Procedia, 2017, Vol. 25, pp. 4296–4310.

[17] Jurlina Alibegović, D., Kordelj De Villa, Ž., Šagovac, M.: Smart City Indicators: Can They Improve Governance in Croatian Large Cities?, Radni materijali Ekonomskog instituta Zagreb, Zagreb, 2018, No. 5, pp.1-54.

[18] https://www.localizingthesdgs.org/library/232/ICLEI-Briefing-Sheets-02-Cities-and-the-Sustainable-Development-Goals.pdf

[19] https://smartcitiescouncil.com/

[20] https://medium.com/@iostoken/the-internet-of-services-intro-to-our-tech-e91abfb13b8c

[21] https://kaplblog.wordpress.com/portfolio/mumbai-needs-smart-mobility/

[22] https://geographica.com/en/blog/what-is-smart-mobility/

[23] https://www2.deloitte.com/content/dam/insights/us/articles/4331_Deloitte-City-Mobility Index/Amsterdam_GlobalCityMobility_WEB.pdf

[24] https://www.helsinkibusinesshub.fi/smart-mobility/

[25] https://www2.deloitte.com/content/dam/insights/us/articles/4331_Deloitte-City-Mobility-Index/Helsinki_GlobalCityMobility_WEB.pdf

[26] https://investinaustria.at/en/blog/2019/06/future-mobility.php

[27] https://www.tportal.hr/tehno/clanak/domaca-aplikacija-umjesto-vas-trazi-i-placa-parking-a-vec-je-dostupna-u-osam-gradova-foto-20180416

[28] http://smart-transportation.org/smart-mobility/

[29] http://www.zagrebparking.hr/default.aspx?id=139

[30] https://www.ebikezagreb.com/book-electric-bike/

[31] https://www.spincity.hr/en

[32] http://smart-ri.hr/

[33] http://www.rijekapromet.hr/hr/automatsko_upravljanje_prometom/5/16

[34] https://slobodnadalmacija.hr/novosti/biznis/clanak/id/522029/39split-parking39--aplikacija-smart-splitparking-u-svjetskom-je-vrhu

[35] https://www.pulainfo.hr/hr/where/elektricni-bicikli-za-razgled-grada

[36] https://www.zadar.travel/en/journey-planner/smart-bike-system#.XRusTeszbIU

[37] https://www.liberoportal.hr/vijesti/1900-senzora-dubrovnik-ispred-svjetskih-gradova-u-projektu-smart-parking-ovako-ce-funkcionirati-foto

[38] https://www.srednja.hr/novosti/arriva-croatia-mobilnu-aplikaciju-putnici-stede-vrijeme-novac/

[39] https://www.croatiaweek.com/jadrolinija-ferries-launch-new-mobile-app-facilitating-ticket-purchases/

[40] https://www.osijek.hr/i-share-life-projekt/

[41] https://www.un.org/sustainabledevelopment/wp-content/uploads/2018/09/Goal-11.pdf

[42] http://www.smart-world.org/2019/iop/

[43] Grad Zagreb, Okvirna strategija pametnog grada Zagreba – Zagreb smart city, vizija do 2030. Godine, Zagreb, 2018.

[44] Šojat, D.: Doprinos indikatora mobilnosti pametnom gradu, Fakultet prometnih znanosti Sveučilišta u Zagrebu, Zbornik radova okruglog stola, Zagreb, 2017, pp. 28-37.

[45] Washburn, D., Sindhu, U., Balaouras, S., Dines, R. A., Hayes, N. M., Nelson, L. E.: Helping CIOs Understand "Smart City" Initiatives: Defining the Smart City, Its Drivers, and the Role of the CIO. Cambridge, MA: Forrester Research, Inc., 2010.

PROSPECTS FOR THE NORTHERN SEA ROUTE DEVELOPMENT: ECONOMIC AND ENVIRONMENTAL ASPECTS

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Summary

Maritime transport is an important branch of the Intelligent Transport System (ITS). Modern ITS technologies can significantly improve the performance of container terminals, as well as affect the global productivity of maritime transport. The Arctic is a large energy region with easy access to the sea for the transportation of crude oil and liquefied natural gas. This investment direction is a priority for Russia, and number of other countries, including China, since it will promote interests in the field of energy and shipping. Tankers with icebreaker capabilities carry crude oil and natural gas from the Russian Far East to Western markets and make up about 45% of ship traffic on the Northern Sea Route (NSR). Other shipments are carried out by ice-class tankers of the large Russian project Yamal LNG, and also natural gas is transported from the port of Sabetta to Europe. Although the NSR is a direct route, this does not make it simpler. There are no transit ports or transhipment points for efficient distribution of goods. There are a number of other equally important operational limitations. Thus, some sections of the route are too small for large container ships. There are environmental issues, such as the elimination of an oil spill on ice. The article analyses the economic and environmental aspects of expanding the possibilities of using the NSR as an alternative route from Europe to Asia.

Keywords: Northern Sea Route, sea shipping, icebreaking fleet

1. INTRODUCTION

Maritime transport is an important branch of the Intelligent Transport System (ITS). Modern ITS technologies can significantly improve the performance of container terminals, as well as affect the global productivity of maritime transport.

To organizing international cargo transportation, the sea transport in many countries [1] share is dominated (up to 85%), which can be explained by its advantages:

- low cost and price;
- sea vessels' large cargo capacity and their versatility, which allows heavy weights bulk demand one-time transportation.

Sea transport shipping is 90% of the cargo total volume which transported during international trade [2]. Sea transportation is the most important, cheap and convenient transcontinental shipping's component. In this case, then greater the cargo transported volume, by that maritime transport is more efficient. However, for sea shipping there are significant limitations:

- low goods shipping's speed;
- high costs for the ships production and specially equipped sea ports;
- significant costs for the ship's operation and infrastructure (sea ports, terminals, etc.);
- environmental problems associated with diesel ship engine emissions, especially in densely populated coastal areas and port cities.

Major maritime trade routes: North Atlantic; Caribbean; Europe - South America; South American; South Pacific; North Pacific; Mediterranean Sea - South Asia - Australia; South African. The shipping intensity in the various oceans waters is different and is currently: The Atlantic Ocean - 60%; The Pacific Ocean - 25%; The Indian Ocean - 15% of world shipping. In the Arctic Ocean waters, the maritime shipping volume remains insignificant, although it is growing annually. However, taking into account the above, as well as the fact that the maritime transport routes development and maritime navigation requires significant investments, a such projects prospects' detailed study is necessary, taking into account all economic and environmental factors and risks.

The topicality of integrated marine environmental management in the Arctic, based on the ecosystem approach, is obvious. This is evidenced not only by the Arctic Council and its working groups activities, but also by wider international activities to implement the sustainable development goals agreed in the UN in 2015, in particular, goal 14 ("Conservation and rational use of oceans, seas and marine resources in sustainable development"), which preserves the most valuable and vulnerable water areas, protects biological diversity and marine ecosystems. As part of this goal, in particular, the problem has been set to implement environmental measures in at least 10% of coastal and marine areas by 2020, taking into account the marine ecosystem coverage representativeness [3] (in 2017, protected status covered 5.3% of all marine spaces in world [42]). Therefore, it is important to strategic planning and forecasting in the evolution programs development and infrastructure projects, taking into account the risks and consequences for both the short and long term.

2. RESEARCH METHODS

This article main goal was to study the NSR potential, to summarize the of studies results, which performed by scientists and confirmed by practitioners, as well as to hypothesize the possibility of planning sustainable logistics routes using the NSR. Accordingly, Chapter 2 describes the NSR potential, the shipping characteristics at high latitudes, as well as the main directions of scientific research on this topic.

The cargo shipping specifics at now is the tendency toward an increase in the size and carrying capacity of container ships. Thus, the largest container ship in the world - the CMA CGM Antoine de Saint Exupéry, with a 21,000 TEU capacity, 400 m long and 59 m wide, was put into operation in 2018. Along with this, there are innovative solutions for shipping and navigation systems that will bring the process of cargo shipping to a new level. So, the world's first autonomous cargo ship - a small-sized electric container ship designed to transport 100-150 containers - is planned to be launched this year. It will transport fertilizers along the 37-mile route off the Norway southern coast from the Yara International production site in Porsgrunn to the Larvik port.

Such changes will inevitably affect the infrastructure (sea ports, terminals, dry ports, etc.). For this reason, at the first stage, we identified the main strategic directions, the development of which should be carried out in parallel to ensure the required efficiency, sustainability and safety of the transport system (Fig. 1a).

At the second stage, risks that are inherent in these areas of development, the causes of their occurrence and methods of solution should be identified. For a qualitative analysis, you can use the tree method (an example in Figure 1b).

The next stage is to assess the possibility of using the existing NSR potential and the main strategic directions for its expansion. For these purposes, a system of performance indicators should be developed (Figure 1c) .

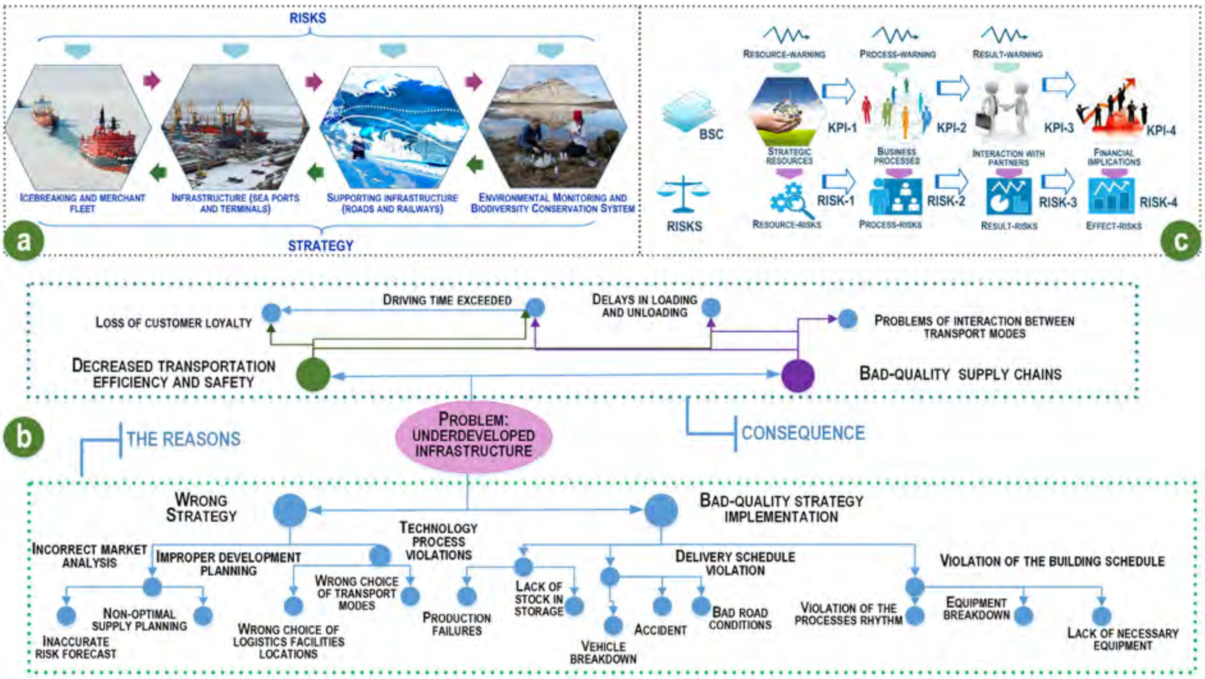

Figure 1.

3. PROBLEM STATE: NSR DEVELOPMENT PROSPECTS AND ALTERNATIVE ROUTES

In 2008, the unprecedented melting of Arctic ice reduced the ice cover to 1 million square kilometers, for the first time temporarily freeing it from ice and, thus, opening the North-West Passage and the Northern Sea Route for non-icebreaking vessels [5]. The sea ice retreat suggests the possibility of future safe and efficient the Arctic sea shipping. This provides opportunities for commercial traffic due to shorter distances up to 40% between Asia and Europe. It is estimated that about 5% of world trade can be made through the Northern Sea Route (NSR) with year-round and unimpeded navigation in the Arctic. This prince's additional income for many countries in Europe and East Asia.

3.1. Prospects for shipping in the northern latitudes

The Arctic is a large energy region with easy access to the sea for the transportation of crude oil and liquefied natural gas. This investment direction is a priority for Russia, and number of other countries, including China, since it will promote interests in the field of energy and shipping. Currently, there are two alternative routes in the Arctic: the North-West and North-East (Fig. 2).

The Northwest Passage forms a series of different possible paths between the 19,000 islands of the Canadian Arctic Archipelago. The Northwest Passage is deep enough to accept supertankers and container ships, whose draft is too large for the Panama Canal [6]. However, in the near future, the passage is not of interest from the commercial navigation development point of view due to the weather conditions extreme unpredictability of the Canadian Arctic Archipelago, which makes potential rescue operations too complicated and cargo insurance too expensive. Navigating the Northwest Passage is very difficult due to heavy multi-year ice, difficult straits and a pingo (bottom ice formations protruding from the seabed) [7].

The article authors [8] show that the sea routes in the Canadian Arctic Archipelago are complicated and include several routes. The authors analyze the vessels types and the vessels ownership structure that sailing in the Canadian northern waters, as well as the cargo types and their tonnage. This allows us to study the delivery routes schemes and their dynamics over the past decade. The network structure of various product groups indicates a trade's models' variety in the Arctic waters between the Canadian and foreign fleets. In assessing future trends, the document identifies the main problems from point of view in market changes, regulatory regimes and risk.

Figure 2. Alternative Arctic routes (a) and sea shipping statistics (b)

The paper [9] discusses two different routes from Europe to Southeast Asia through the Arctic Ocean seas: The Northern Sea Route (NSR) and the Northwest Passage. Some alternatives to the NSR and the Northwest Passage are described: a) by sea - a transport artery running along the Suez Canal; b) by land - these are transport arteries, including the Trans-Siberian Railway (TransSib). The study aims to create a model of international transport corridor. The model is based on an autoregressive distributed lag model (ADL). individual models were built for the Northern Corridor, the Trans-Siberian Railway, the Suez Canal's transport corridor and the Northwest Passage. The factors influencing the model's endogenous variable consisting of the goods volume transported along all corridors are analyzed.

The Northwest Passage can become competitive to other Arctic transport corridors, as well as an alternative to passing through the Panama Canal only in the progressive climate change event in the region. According to available forecasts, ice in the Arctic will begin to disappear almost completely in September (the month of the Arctic ice greatest melting) by 2050 [10]. In addition, this route's evolution is hampered by the infrastructure development low degree, as well as its passage through the territories, which, unlike the NSR, are undeveloped in terms of the natural resources extraction, for these reasons, the passage can only be used for transit between the initial and final route points, without the loading ships possibility at intermediate points.

A Northeast Passage's significant part is the Northern Sea Route, so many sources use both terms as synonyms. The main difference between the Northern Sea Route and the Northeast Passage is that the latter includes the Barents Sea and provides access to the Murmansk port, the largest Arctic port in Russia. The Northern Sea Route runs along the northern Russia coast along the Arctic Ocean seas (Barents, Kara, Laptevs, East Siberian, Chukotka and Bering), unites the European and Far Eastern Russian ports and the mouths of navigable Siberian rivers into a single transport system. The Northern Sea Route's length from the Kara Gates to the Providence Bay is 5.6 thousand km.

Of the three Arctic sea routes, the Northern Sea Route and the Northeast Passage in general have the most significant potential for economic activities in the Arctic. There are two possibilities here: transit shipping with the goods transportation between non-Arctic ports and targeted shipping with activities that begin or end in the Arctic. Such activities include fishing, tourist cruises, scientific expeditions and resource extraction. Among them, the resources extraction is a sector that allows the transport operations' development in the shortest possible time - in the resources transportation form of the region to the west to Europe or to the east to Asia.

The large reserves of energy resources and mineral resources in the Eurasian Arctic and the presence of Russian icebreaker escort have led to the fact that targeted shipping oriented towards the resources transportation has become the most cost-effective form of maritime commercial activity on the Northern Sea Route. Thouse resources include oil, gas and minerals, such as phosphates, nickel, copper and others.

Cargo turnover on the Northern Sea Route (NSR) is growing. Tankers with icebreaker capabilities carry crude oil and natural gas from the Russian Far East to Western markets. Oil tankers make up about 45% of ship traffic on the NSR. Other shipments are carried out by ice-class tankers of the large Russian project Yamal LNG, and also natural gas is transported from the port of Sabetta to Europe.

3.2. Test runs to study the northern routes prospects

Global climate change creates both risks and opportunities in the North Pole's adjacent areas. Those countries and companies that could use these opportunities began to compete for the initiative to develop the region. For example, in 2013, the Korean shipping company conducted test navigation between Russia and Korea through the NSR. The article authors [11] analyzed the economic, external and internal driving forces and barriers for using the NSR from the shipping companies' point of view. Comparative case studies show that the differences between shipping companies that consider navigating the NSR mainly consist in the economic opportunities companies' perception and their internal factors. Despite the economic and external political barriers, financial opportunities and company's leadership played a key role in exploring the new route, finding the potential for the resources delivery from the Arctic region.

The route between Asia and Europe along the NSR can significantly save energy and reduce pollution compared to conventional southern routes. The article [12] authors give an analysis from the COSCO point of view, the largest Chinese container shipping operator. This is a cost-benefit analysis on several scenarios, taking into account the following current realities: (1) a decline in oil prices that has not been observed for decades, even lower than the lowest prices assumed in previous studies; (2) the Russian NSR tariff reduction as an attempt to attract freight traffic; (3) possible emission control zones along the northern route may require much cleaner energy and, therefore, affect costs that have not been studied in previous models; and (4) the difference in capital costs between a rented and owned ship. For comparison, classic case studies of shipping routes between Shanghai and Rotterdam are taken. The authors explain how various factors influence the delivery cost and to what extent the NSR can be economically viable. Thus, the route can be economically competitive in total profit terms received for continuous use.

In the summer of 2017, the Chinese expedition for the first time on the icebreaker “Xuelong” (figure 3b) successfully crossed the Arctic Ocean's central channel of the and passed through the Transpolar Passage [13]. However, the passage of “Xuelong” was accompanied by stops and periodic drift stay, which calls into question the possibility of providing reliable year-round navigation without the powerful icebreakers' help. In the near future, such an route requires not only icebreakers, but also conducted vessels. Of the three Arctic transport corridors, the icebreaking system is used only by Russia along the NSR, which allows not only increasing the ships navigation safety across ice, reducing the risks associated with single navigation in polar regions, but also significantly expanding their safe operation as by season so and by navigation area.

In 2018, the first container ship Venta by MaerskLine (figure 3a), the largest container shipping company in the world, the Danish company Maersk, passed through the Northern Sea Route (NSR) from Vladivostok to St. Petersburg. Venta Maersk - a medium-sized container ship built to the order of the company and launched in 2018, capable of transporting 3.600 standard containers. The container ship loaded with refrigerators with fish products departured from Nakhodka to the South Korean Busan port, it was loaded with electronics and set off to St. Petersburg. The economy was 10 days compared with shipping through Suez. The Cosco shipping line also shipped around a dozen general cargo ships (multi-purpose dry cargo ships). The fact that a world-famous company made a test route run with its new ship, whose crew, moreover, did not have experience shipping in the Arctic, suggests that the SMP is not just interesting, but can provide a real alternative to the established trade routes from South -Eastern Asia to Europe. (Figure 3c). Russia needs to provide an economically attractive high-level services' full diapason for reliable cargoes delivery just in time under any ice conditions. NSR can compete with the southern routes if it provides year-round icebreaking shipping, full navigation and hydrographic services, and an emergency rescue system. All this is impossible without the new icebreaking fleet construction and port infrastructure in the Arctic. To solve all these problems, an integrated project for the Northern Sea Route development is being implemented.

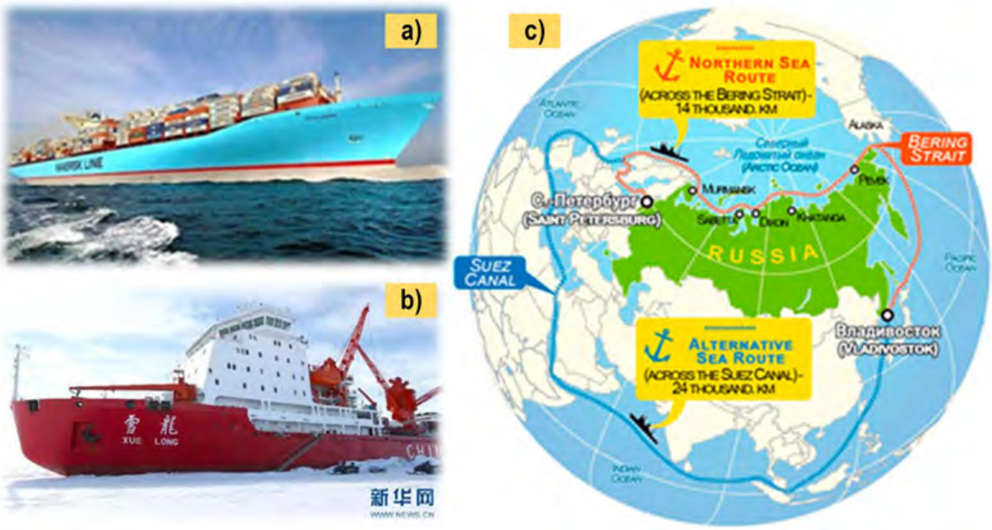

Figure 3. a) Vessel Venta Maersk during the passage of the test route Vladivostok - St. Petersburg on the NSR; b) Chinese icebreaker "Xuelong" ("Snow Dragon"); c) Alternative sea route

3.3. Research on the prospects and risks of NSR developing

Until recently, the severe environmental conditions during the year significantly hampered the necessary access and transport links in the Arctic. However, now the Arctic is seen as a promising area for economic activity and as a potential linking corridor between Asia and Europe / America. The article [14] authors state that since activity is expected to increase in this region, it is imperative to assess the current support level for courts that will cross the region; as well as opportunities related to search and rescue (SAR) and oil spill response. While various alternative sea routes have been proposed for the Arctic, NSR is the most promising since the Russian state has already invested heavily in the icebreaker's construction, and their current number is quite coping capable with the limited traffic current level. On the other hand, at present, ships are faced with large distances to overcome (often without adequate support) adverse environmental conditions, unpredictable obstacles and a slow response time in emergency case. In any case, if the SMP becomes fully integrated into the global shipping system, further research is needed to discuss the implications at both the regional and global levels.

The negative environmental consequences of navigation in the Arctic need to be investigated and controlled. To understand the shipping impact in the arctic areas, the method described in article [15] determines the travel time, fuel consumption and the corresponding exhaust emissions of ships navigating in arctic waters. In the examples studied, the vessel features are studied, as well as environmental conditions with a special focus on ice scenarios. Travel time, fuel consumption and exhaust emissions were investigated for three different ships using NSR different passages in different seasons in 1960s, 2000s and 2040s.

The article [16] main purpose is to identify key criteria that influence the shipping operator's decisions in relation to the Arctic sea routes using. The making multi-criteria decisions method, the fuzzy analytical hierarchy process, is used to rank the four potential categories of criteria ("economic", "technical", "political" and "security factors") and their subcriteria. The analysis results show that, in aggregate, "economic" are the most important influential factors category, followed by "security", "technical" and "political" factors. However, the paper concludes that the most influential specific subcriteria relate to risks that lie mainly in the areas of "security" and "politics", and that, especially in combination, they exceed the importance attached to "economic" factors such as with decreasing fuel consumption. Finally, these findings implications for the future Arctic shipping development are considered at a strategic level.

A greater vessels number passing through the NSR means an increased accidents risk and associated oil spills. Previous studies show that the existing infrastructure is not enough to increase shipping. Therefore, if an oil spill occurs, the window for successful cleaning will be short. The article [17] authors believe that it is necessary to take into account the long-term unrestored pollutants fate, at least until the next melting season, when it becomes available again. They explore the ocean advection role in determining the long-term Arctic pollutants fate using a high-resolution ocean model along with Lagrangian particle tracking to model the pollutants spread. The resulting pollutants "advective traces" are offered as an informative metric for analyzing such experiments. Circulation in NSR different parts is characterized based on the fact that there are three main regions in the Eurasian Arctic, so the characteristic circulation paths for each of them are associated with the long-term spilled oil fate.

The traveling variant from Asia to Europe along the NSR is considered as a worthy solution for reducing fuel consumption and increasing the time efficiency when cargo delivering to a chosen destination. But at the same time, it is necessary to solve the ensuring safety task the ship structures against collisions with obstacles that may be encountered in the Arctic. Hard ice can be considered as a serious threat to the ship's structures double bottom during shock events, especially when landing ships. The article [18]] conducts a landing calculations series to estimate the structural impact resistance in the double-bottom interaction with conic-type ice.

Modeling and IT using to improve the northern routes safety is a reliable tool in the research of many scientists. Thus, the study goal [19] is to determine the navigation efficiency for transit from various Asian ports and European Rotterdam via the Northern Sea Route. Navigation efficiency was authors determined by the fuel consumption. Preliminary research results showed that fuel consumption and carbon dioxide emissions were reduced due to transit from various ports via the European Sea Route, and navigation efficiency at various ports was ranked in the following order: Yokohama - Busan - Shanghai - Kaohsiung - Hong Kong - Singapore. The higher this ratio, the lower the NSR using's navigational efficiency, i.e., more fuel was consumed, and travel expenses were higher. In contrast, the lower this ratio, the higher the navigation efficiency, i.e., less fuel is consumed, and transport costs are lower. The study [20] authors proposed a general mathematical formulation based on spatio-temporal networks for analyzing the ship routing problem and cargo assignment when shipping liners and applying it to the NSR planning problem. To solve this problem, they proposed an expansion algorithm based on Lagrangian relaxation, which facilitates the network operation. Empirical results have shown that navigation skills, bunker cost, delay penalty and service engagement are the main factors affecting the NSR navigating commercial viability.

To carry out a comprehensive analysis of the NSR transit traffic current state and its future prospects, in 2015, the project "Feasibility and Reliability of Shipping on the Northern Sea Route and Modeling of an Arctic Marine Transportation & Logistics System" was created. The project involved numerous representatives from industry, government agencies and research groups from Europe, Asia and Russia, what assured a unique and comprehensive subject overview. The article basis [21] was the results obtained during the project implementation. Firstly, it contains a comprehensive overview of current regulations and support services to NSR. Secondly, information on the route's current state is combined with feedback received from stakeholders during the project discussions, with the goal of creating several possible future operational models for NSR transit traffic. It is concluded that the most likely of the analyzed operational models is a combination of ships reinforced ice class and independent ice cargo ships. A viable option in the future is also the transshipment hubs creation at each end of the NSR with ice cargo ships passing between them.

The Arctic development and its transportation are associated with significant risks caused by this region unique features, such as ice, severe operating conditions, unpredictable climatic changes and remoteness. Given the uncertainty high degree both for the ship's systems operation and for the people who govern them, reliable risk analysis and management tools are needed to provide decision support for accident prevention and safety at sea. The article [22] proposes a model of an object-oriented Bayesian network for dynamic probability prediction of a ship's collision and ice based on the navigation and operating system state, weather and ice conditions, and human errors. A model, when integrated with potential consequences, can help assess risk.

Sea shipping is at risk to potential accidents leading to damage to ships, crew members and the ecosystem. The navigation safety, especially in arctic waters, is a growing concern. The study [23] proposes a new risk model applicable to the NSR to study the marine accidents possibility, such as collision, foundering and grounding. The model is developed using the Bayesian network (BN). The proposed risk model takes into account the various operational and environmental factors that affect supply operations. The model is demonstrated using the oil tanker research example that navigates through the NSR. The model suggests that the ice effect is the dominant factor in the incident. The case study illustrates the model priority when investigating the accidents operational risk. Risk assessment provides early warning to take appropriate preventive and mitigation measures to improve the shipping operations overall safety. The article [24] proposes a solution model for the ship-owner who considers the advantages of sailing north along the NSR or south along the Suez Canal (SCR) when transporting petroleum products from Russia to Asia. The decision is based on potential savings in costs and travel time, which change monthly depending on the navigation conditions and the area along the NSR. This study applies to the Panamax 1A Ice-Class tanker passing through the NSR, as compared to the Panamax tanker passing through the SCR. It concludes that the NSR provides a competitive advantage in the months from August to November, when conservative assumptions about ice conditions (upper limit) are taken into account for the ice thickness level encountered along the route, and from July to November, when the lower limit is expected.

The twenty-first century is the IT-era, so route planning plays an important role in the navigation field. Article [25] presents an improved route planning algorithm based on the A* algorithm. A certain turning points number for route planning is established primarily by sorting and analyzing ENC data on s-57 diagrams. Secondly, a database is created to store route points. Third, for route planning in the improved A* algorithm the simplified distance calculation formula and the Haversine formula are used. Finally, to test the proposed algorithm, a route planning platform in the North China Sea based on ArcGIS Engine was developed. The analysis results show that it is possible to find the optimal path between each coastal port in the North China Sea.

The NSR sea transport flows' analysis differs significantly from other transport types, because navigation follows the recommended routes, i.e. there are no clear boundary conditions for the movement and vessel parameters. The movement largely depends on the ice conditions and hydro-meteorological conditions, with which there is a constant interaction. The GIS for the NSR developed by the article [26] authors makes it possible to calculate potential hazard models that are taken depending on the following criteria: distances between ships, course intersections, ice conditions and navigation area's hydrographic study.

The article [27] proposes to use a geographic information system (GIS), which includes data on the speed and various capacities ships routes, as well as Earth's remote sensing data on ice conditions. Traditional routes' two parts in the Russian Arctic western part were considered: the sea passage from the Barents Sea to the Kara Sea through the Kars Strait and the transition from the Barents Sea to the Kara Sea through the Cape of Desire. These data's joint study on the 2018 winter navigation example provides detailed information on the ships speed decrease trends in fully consolidated ice. Based on the study results, the data for four vessels groups with different gross tonnage, capacity, ice passage and draft are presented.

4. RESULTS AND DISCUSSIONS

The NSR becomes not only the shortest waterway between European Russia and the Far East, but also a unique transcontinental route which considerable interest to the many world countries' economies. An important role in the northern territories' life, the fisheries development, trade, international and interregional economic relations play seaports and terminals.

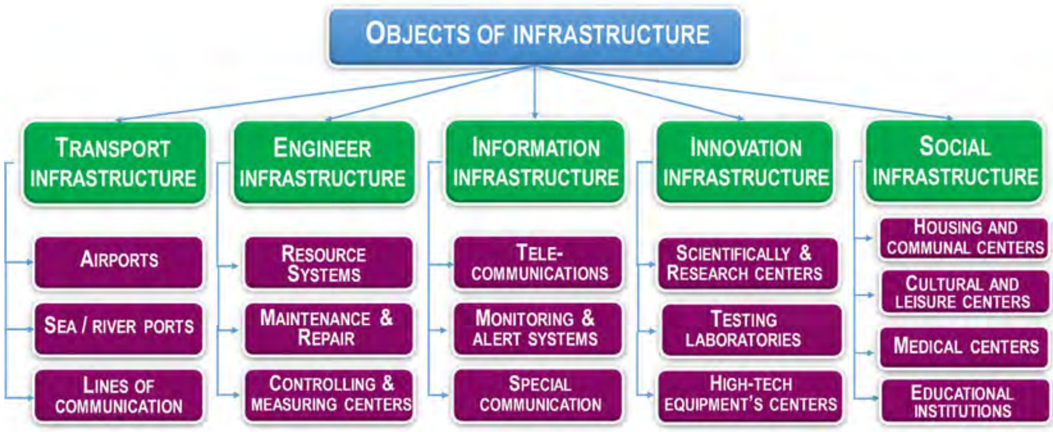

Figure 4. Classification of infrastructure objects

Ports of the White and Barents Seas, as well as Far East ports are located outside the NSR waters, but are essential for its operation. Cargo flows are formed in them, icebreaker escorts are based, and comprehensive ship servicing is carried out. And since the climatic conditions in the region are extreme and the prerequisites for development are initially absent, that such territories development is possible only with active government participation, including the ports development, aimed at creating a modern material and technical base, establishing order and rules for their functioning, meeting the needs of the economy and life support North territories. The infrastructure projects composition is shown in Figure 4.

3.1. Directions for increasing the NSR capacity

The development of the Arctic is planned through a so-called "reference zones" system. In total, eight such zones have been created, one of which is Arkhangelsk zone. The zones support task is to link all the projects and resources that are on their territory for the socio-economic activity's development in the Arctic zone and to obtain the maximum synergistic effect. The Murmansk and Arkhangelsk northern ports are prime importance. Without developing them, it is impossible to count on the shipping development along the NSR, the Arctic deposits development, and in the future - the shelf and Eastern Siberia coastal areas with their gigantic natural resource's reserves. The Russia geographical position leads to the ports development in the northern and Arctic seas, despite the technical difficulties and the high construction cost. It should be noted for comparison that almost the entire metallurgical industry of Finland and Sweden is concentrated in the North of the Gulf of Bothnia on the Baltic Sea at the same latitudes as the Arkhangelsk port. Therefore, the building idea a new deep-water area of the Arkhangelsk sea trading port with simultaneous icebreaker fleet replenishment is quite attractive. Arkhangelsk port extension will significantly improve interaction with the Urals region, subject to the simultaneous Belkomur (White Sea-Komi-Urals) railroad building through the Perm Region and the Komi Republic. An opening up route to Kazakhstan, which is a Russian ally within the Customs Union and has a fast and efficiently developing economy, as well as further rail access to China and Japan, is becoming promising.

The NSR connection with railways in the country's western part, pipeline exits' provision to the terminals for the shipment of liquid hydrocarbons to sea tankers, and the setting to the northern coast of delivery other minerals routes plays an important role in the transport tasks fulfillment of the Russian Arctic zone. The Arkhangelsk Sea Port deep-water area development is closely related to the Belkomur project implementation. The Belkomur project is included in the Strategy for the Development of Railway Transport in Russia until 2030 and will be implemented on the public-private partnership basis with state support. The project involves the railroad construction in the direction of Solikamsk - Gainy - Syktyvkar - Arkhangelsk (length 1155 km).

However, the Belkomur project acquires special significance for shippers only in the case of a synchronous implementation for the Arkhangelsk port new deep-water area construction project, thereby ensuring optimal transport-logistics links scheme (with the shortest train leg, an inexpensive and highly efficient modern port, providing convenient access to the North Atlantic), aimed at the RF relations development with trading partners in the commodity markets of the EU, North and South America, Central and South -Eastern Asia.

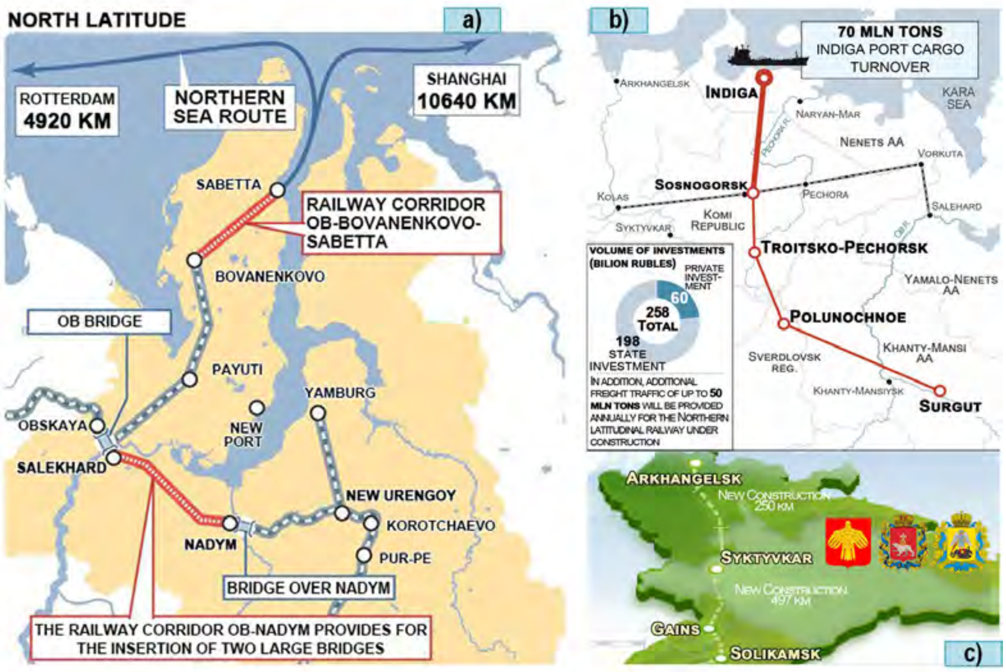

Figure 5. Infrastructure projects for NSR capacity growth: (a) the northern latitudinal way, (b) the Indiga port; (c) Belkomur.

The large modern seaport near Arkhangelsk emergence with independent access to the World Ocean will play an important role in the Russian export and transit potential realization and will be one of the most promising from point of view respect for the Russian Federation strategic interests. In addition, the effective Northern Sea Route functioning, as an international transport corridor, will be largely determined by the NSR eastern shoulder's exploitation - the Far East seaports. At the same time, the Petropavlovsk-Kamchatsky seaport geographical position gives every reason to consider it as one of the key ports on the NSR eastern shoulder.

4.2. Icebreaking fleet and its role in improving the NSR functioning sustainability

Geographically, the northern ports are located near the new industrial complexes creation places in the most convenient places on the peripheral seas' shores Arctic Ocean and the lower reaches of deep-water rivers (Yenisei, Khatanga, Lena, Kolyma). A transit cargo traffic analysis shows that the NSR will function efficiently from an economic point of view if it has a large-tonnage fleet, since now the main cargoes for the NSR are gas and oil. Therefore, it is necessary to study the theory and practice of large-tonnage vessels pilotage and to select the optimal schemes for vessels pilotage, to solve the problems of too small depth for large tonnage vessels on traditional routes. Hydrographic studies are required to ensure the new high-latitude deep-water routes formation. Along with the creation of reliable hydrographic, hydro-meteorological support, work is needed to create seven basic reference points: in Sabetta, Dudinka, Dixon, Tiksi, Pevek, the port of Provideniya and Anadyr [28, 29].

The Russian atomic icebreaking fleet role is also increasing. Until recently, nine linear icebreakers operated on the NSR routes (Table 1). Of these, five nuclear, including the nuclear-powered icebreaker “50 years of Victory”, built in 2007, and four diesel ones.

Table 1. Russian Icebreaking fleet

Linear icebreakers operating today on the NSR routes	Commissioning year	Owner, home port	Notes
		Nuclear icebreakers	
50 years of Victory	2007	FSUE “Atomflot”, Murmansk	
Yamal	1992	-”-	
Taimyr	1989	-”-	The main areas of work are the beds and mouths of Siberian rivers.
Vaigach	1990	-”-	
		Diesel electric icebreakers	
Admiral Makarov	1975		Russian Federation, Vladivostok
Krasin	1976	-”-	
Captain Dranitsyn	1980	Russian Federation, Murmansk	The main areas of work are the beds and mouths of Siberian rivers.
Captain Khlebnikov	1981	OJSC Far Eastern Shipping Company, Vladivostok	Certified as a passenger ship

For the icebreaking fleet renewal and development, the federal target program “Development of the Russia transport system (2010-2015)” was adopted. In this program frame, in 2012, a 25 MW icebreaker began construction at the Baltiysky Zavod and a 16 MW ice breaker at the Vyborg Shipyard. Atomic icebreakers are currently the key to the Arctic development. The main such vessels advantage is the navigation autonomy, which is several months without entering the port for reloading. There is an understanding of this in all the Arctic states, but today only Russia have this class ships. Now, the nuclear icebreaking fleet consists of two nuclear icebreakers with a two-reactor nuclear power plant with a capacity of 75 thousand horsepower (“Yamal”, “50 Years of Victory”), two ice-breakers with a single-reactor power plant with a capacity of about 50 thousand horsepower (“Taimyr”, “Vaigach”), nuclear lighter carrier-container ship “Sevmorput” and five technological service's vessels.

In 2013, Rosatom announced two open tenders for the construction of serial universal nuclear icebreakers in frame project 22220. On their construction lasted five years. The “Arctic” and “Siberia” have already been launched, and the "Ural" is still on the building berth. The "Arctic" is scheduled to be commissioned in the first half of 2019, "Siberia" in November 2020 and "Urals" in November 2021. According to its technical characteristics, the universal nuclear icebreaker of the project 22220 will be able to work equally effectively in the Siberian rivers mouths and on the NSR. In addition, these nuclear-powered ships will become the largest and most powerful in the world, but at the increased width expense (34 meters instead of 30 on nuclear-powered "Arctic" type ships).

The icebreakers of the project 22220 have, in addition to the nuclear installation, electro-engine systems, which significantly reduces the cost of their operation and facilitates the crew's work, and the new nuclear reactor will allow more than six months to not enter the port for recharging. The reactors work not only for steam turbines, which in turn rotate the propeller shafts, they act as power plants, supplying current to all vessel's consumers, including engines, which distinguishes them from the previous generation icebreakers. Icebreakers of the project 22220 will be able in the Arctic conditions to spend ships caravans, including tankers with a displacement of up to 70 thousand tons, punching ice up to three meters thick in the movement course. New Icebreakers will to conduct ships carrying hydrocarbon raw materials from the fields of the Yamal and Gydan peninsulas, the Kara Sea shelf to the Asia-Pacific region markets. Two-draught vessels design with an adjustable immersion depth allows their use both in the Arctic waters and in the polar rivers estuaries.

According to the icebreaker fleet modernization projects, by 2035 the Arctic fleet should consist of 5 nuclear icebreakers with a 60 MW capacity, three icebreakers "Leader" with a 120 MW capacity, four icebreakers on gas engine fuel with a 40 MW capacity and the nuclear icebreaker "50 Years of Victory", put into operation in 2007. In addition to icebreakers in the Arctic, ice-class vessels also go - tankers, suppliers, etc. In addition, a new project, more powerful Russian atomic icebreaker 10510 Leader (with a 120 MW capacity) is being prepared. The main tasks of the new nuclear-powered ships should be to ensure year-round navigation along the NSR and expeditions to the Arctic. Russian Icebreaking fleet is the largest in the world. Other Arctic countries, neither now nor in the coming years, will be able to compete with Russia in the quantity and quality of ice-breaking resources.

For example, the United States has only three heavy diesel-electric icebreakers (run by the coast guard), two of which have been operating for 30 years. At the same time, the power of American icebreakers is much less than the Russian ones. The resulting disparity causes concern to some representatives of the American authorities. In 2015, the Coast Guard Commander P. Tsukunft said to the question about the rivalry between Russia and the United States in the Arctic: "Today we are not even in the same league with Russia." In this regard, at the moment, the US authorities are considering the allocation of $ 9 billion for the needs of the coast guard, including the construction of two more non-nuclear icebreakers. However, even such a measure is unlikely to allow Americans to significantly reduce the backlog from Russia.

The Canadian icebreaking fleet is also significantly consede to the Russian in terms for functioning ships number. Of the 17 diesel electric icebreakers, only 3-4 are functioning, the others have reached the end of their service life. The Government of Canada announced the allocation of $ 550 million to replace the flagship vessel "CCGS Louis S. St. Laurent ", plans also to produce four military icebreakers. Approximately the same situation in the Scandinavian countries. Sweden, like Finland, has 7 icebreakers, Denmark - 4, Norway - 1. In addition, a number of non-Arctic states have to one ship each: China, South Korea, Germany.

Currently, it is planned to build ships providing the fleet: atomic icebreakers for year-round operation of transport ships on the NSR; diesel-electric icebreakers for servicing deposits on the northern seas shelves; multifunctional rescue vessels; new generation tugs; technical rescue's means from offshore oil and gas facilities in ice conditions. This, in accordance with the transport strategy of Russia for the period up to 2030, will make it possible to create full-fledged conditions for the provision and maintenance of transit along the NSR. During the ports functioning, constant work is required to ensure the coastal navigational aids operability, including the GLONASS / GPS monitoring and corrective stations network [30]. Currently, the entire Northern Sea Route is covered by a network of control & correction stations, which are located on the islands of Oleniy, Andrew, Stolbovoy, Kamenka, on Cape Sterligov and on the Indigirka River, which can improve the accuracy and authenticity of finding the vessel location coordinates, which, in turn, contributes to the navigation safety [31].

4.3. NSR as a single infrastructure project's part

The Arctic territories' qualitative development is impossible without the infrastructure projects' successful implementation. The Arctic transport system formation is the most important task for the region development. The limited transport system seriously hinders the northern regions development. It is necessary to connect the great Siberian rivers routes to the Northern Sea Route, reconstruct old and build new railways branches, highways, and also massively use aviation, then it will be a powerful transport and logistics system [32, 33]. This task implementation can give a new impetus to the polar regions' innovative development and increase their investment attractiveness. At the end of the twentieth and the beginning of the twenty-first century, there was a tendency to supplement the sectoral regulation of maritime activities' certain types with integrated (cross-border and inter-sectoral) marine spaces' management. In contrast to the sectoral, an integrated approach involves the management decisions development aimed at the optimal combination of all economic activity types in certain marine areas within a single strategy and action program for all nature users.

Another important current trend is the ecosystem approach application in the integrated management of marine spaces in order to ensure sustainable development, protect the marine environment and biodiversity from the pollution effects and the resource exploitation depletion. The main tool for implementing the tasks of integrated marine environmental management based on the ecosystem approach is marine spatial planning. According to the definition of the UNESCO Intergovernmental Oceanographic Commission, marine spatial planning involves the spatial and temporal distribution of human activity in the marine areas in order to solve environmental, economic and social problems [34]. The Strategy for the Maritime Activity Development of the Russian Federation until 2030 also stresses the need to combine mainly sectoral approach to planning the development of maritime activities with integrated approach. Among the perspectiving development ways of the maritime activities' main types in the Strategy are the "introduction and development of integral (inter-sectoral) management at all levels, which considers sea management as an integral management object and is aimed at overcoming the conflict between types of use and preservation of the marine environment", as well as "use and development of marine spatial planning tools" [35].

The Strategy for the Development of the Arctic Zone of the Russian Federation (AZRF) and Ensuring National Security for the Period up to 2020 [36] and the Fundamental Principles of State Policy of the Russian Federation in the Arctic for the Period up to 2020 and Further Perspective [37] emphasize the importance of preserving the marine environment and biodiversity in Arctic. The Russian Arctic development strategy includes the development and testing of integrated management models, in particular, coastal zones in the Arctic regions; ensuring the conservation of the biological diversity of the Arctic flora and fauna in the context of expanding economic activities and global climate change; development and expansion of the network of specially protected natural territories and water areas; organization of complex international research expeditions to study the environment (ice conditions, pollution level of sea waters, marine ecosystems) and the impact on it of observed and predicted climate changes.

5. CONCLUSION AND DIRECTIONS FOR FUTURE RESEARCH

The article analyzes the economic and environmental aspects of using the SMP as an alternative route from Europe to Asia, including the use of the Trans-Siberian rail and sea delivery schemes. After building the infrastructure, NSR can become a full-fledged alternative to the Suez Canal as a transit route, but only if two conditions are met: acceptable political risks and ensuring year-round operation. At the same time, as a channel for the raw materials export from the Arctic, the NSR will be the main route, and the traffic directly volume depends on the pace of northern territories development.

To overcome the barriers and constraints that inhibit the transformation of the Northern Sea Route into a real transport artery, both for the Russia's needs and for other countries' transit flows, it is necessary to bring navigation in the Arctic eastern sector, which lasts only 3.5 months to year-round. To solve this problem, need:

1. upgrade the nuclear icebreaker fleet, completing the construction of nuclear icebreakers two new types: the leading icebreaker with a 110–130 MW capacity and new small-sized icebreakers with an about 40 MW capacity.
2. implement projects for the coastal infrastructure development along the NSR, for this need:
   - turn the Sabetta port into a multifunctional NSR junction, which can be used not only for gas export from Yamal, but also for exporting grain from Siberia, metal from the Urals, Kuzbass coal, and oil products from Tatarstan and Bashkortostan.
   - to implement the creating project of "Northern Latitudinal Railway" (Obskaya-2 - Salekhard - Nadym - Pangody - Novy Urengoy - Korotchaevo) for passage to NSR in the Sabetta region. This railway line capacity should be 7 million tons in the 5th operation year, 14 million tons in the 10th operation year, and in the future, it can be increased to 35 million tons of cargo transported. Bovanenkovo-Sabetta railway's building began in 2017
   - to build a multi-functional year-round Indiga sea port on the Barents Sea coast, whose capacity can reach 30 million tons per year, and create a logistics center. This project is extremely important, since it is almost 3 thousand km from Sabetta to the west through the Karsky Gate to Murmansk, but there is not a single port for ships sailing along the NSR (Fig. 5b).
   - to ensure safe navigation along the NSR, it is necessary to modernize such Arctic ports as Khatanga, Tiksi, Pevek, Dudinka, Dikson, plus to build new ports in the townships area of Kharasavey, Pechenga and Varandey.
3. Create information management's infrastructure. For these purposes, Rosatom intends to create a Arctic shipping situational center in Murmansk within two years. The center will be engaged in laying the best routes in the ice between the cracks, which will optimize the ship-owners' cost, while the Center will work around the clock. In the plan until 2020 provides to create a network of arctic control and correction stations GLONASS / GPS along the NSR

REFERENCES

[1] International transport: yesterday, today, tomorrow. URL: https://www.kp.ru/guide/mezhdunarodnye-gruzoperevozki.html [in Russian]

[2] International sea and river transport. URL: https://continent.net/peterburg/transportnaya-logistika/morskie-perevozki/ [in Russian]

[3] Progress report of the Open Working Group of the General Assembly on Sustainable Development Goals. 30 p. URL: https://sustainabledevelopment.un.org/content/documents/3238summaryallowg.pdf

[4] The Sustainable Development Goals Report 2019. Copyright © 2019 United Nations 62 p. URL: https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf

[5] Smith, L.C., & Stephenson, S.R. (2013). New Trans-Arctic Shipping Routes Navigable by Midcentury. Proceedings of the National Academy of Sciences of the United States of America, 110 (13).

[6] Bajerz M. The legal status of the Northwest Passage and the Arctic sovereignty of Canada: past, present, desired future. Bulletin of Moscow University. Series 25. International Relations and World Politics. 2011. №2. p. 92-128. [in Russian]

[7] Farre A., Valeeva V., Efimov YA. Analysis of the Arctic shipping potential. URL: http://pro-arctic.ru/15/04/2015/expert/15541. [in Russian]

[8] Marie-Andrée Giguère, Claude Comtois, Brian Slack. Constraints on Canadian Arctic maritime connections. Case Studies on Transport Policy 5 (2017) 355–366

[9] K Kikkas and E Romashkina Potential Opportunities for the Arctic Transport Space 2018 IOP Conf. Ser.: Earth Environ. Sci. 180 012016

[10] CHernov V. Kanada vstala v prohode. URL: http://portnews.ru/comments/1687/.

[11] Taedong Lee, Hyun Jung Kim. Barriers of voyaging on the Northern Sea Route: A perspective from shipping Companies. Marine Policy 62 (2015) 264–270

[12] Zheng Wan, Jiawei Ge and Jihong Chen. Energy-Saving Potential and an Economic Feasibility Analysis for an Arctic Route between Shanghai and Rotterdam: Case Study from China's Largest Container Sea Freight Operator. Sustainability 2018, 10, 921.

[13] Bashkatova A. Kitaj ishchet al'ternativu Severnomu morskomu puti. URL: http://www.yktimes.ru/новости/kitay-ishhet-alternativu-severnomu-morskomu-puti/.

[14] Dalaklis, D., Drewniak, M.L. & Schröder-Hinrichs, JU. WMU J Shipping operations support in the «High North»:examining availability of icebreakers along the Northern Sea RouteMarit Affairs (2018) Volume 17, Issue 2, pp 129–147.

[15] Schröder, C., Reimer, N. & Jochmann, P. Environmental impact of exhaust emissions by Arctic shipping. Ambio (2017) Volume 46, Supplement 3, pp 400–409.

[16] Po-Hsing Tseng & Kevin Cullinane (2018) Key criteria influencing the choice of Arctic shipping: a fuzzy analytic hierarchy process model,Maritime Policy & Management, 45:4, 422-438

[17] Kelly, S., Popova, E., Aksenov, Y., Marsh, R., & Yool, A. (2018). Lagrangian modeling of Arctic Ocean circulation pathways: Impact of advection on spread of pollutants. Journal of Geophysical Research: Oceans, 123, 2882–2902.

[18] Holstein, A., Kappas, M., Propastin, P. et al. Oil spill detection in the Kazakhstan sector of the Caspian Sea with the help of ENVISAT ASAR data. Environmental Earth Sciences (2018) 77:198.

[19] J Ming-Tao Chou, Tsung-Yu Chou, Yu-Ru Hsu and Chi-Pao Lu. Fuel Consumption Ratio Analysis for Transiting from Various Ports and Harbours in Asia through the Northern Sea Route. HE JOURNAL OF NAVIGATION (2017), 70, 859–869.

[20] Dung-Ying Lin, Yu-Ting Chang. Ship routing and freight assignment problem for liner shipping: Application to the Northern Sea Route planning problem. Transportation Research Part E 110 (2018) 47–70.

[21] Aleksandar-Saša Milakovića, Bjørn Gunnarsson, Sergey Balmasov, Sungwon Hongc, Kitae Kimc, Peter Schützd, Sören Ehlers. Current status and future operational models for transit shipping along the Northern Sea Route. Marine Policy 94 (2018) 53–60

[22] Bushra Khan, Faisal Khan, Brian Veitch, Ming Yang. An operational risk analysis tool to analyze marine transportation in Arctic waters. Reliability Engineering and System Safety 169 (2018) 485–502

[23] Dung-Ying Lin, Yu-Ting Chang. Ship routing and freight assignment problem for liner shipping: Application to the Northern Sea Route planning problem. Transportation Research Part E 110 (2018) 47–70

[24] Olivier Faury, Pierre Cariou. The Northern Sea Route competitiveness for oil tankers. Transportation Research Part A 94 (2016) 461–4690

[25] J. Yi and Z. Zhenhao, "Route planning based on improved A∗ algorithm," 2017 Chinese Automation Congress (CAC), Jinan, 2017, pp. 6939-6942.

[26] E Ol'khovik. Geoinformation system use for transportations planning in water area of Northern Sea Route. IOP Conf. Series: Earth and Environmental Science 194 (2018) 072010. IPDME2018

[27] A Afonin, E Ol'Khovik, A Tezikov. Study of ship speed regimes in the Arctic sea ice conditions. IOP Conf. Series: Earth and Environmental Science 194 (2018) 072012. IPDME2018

[28] Kiselenko A.N., Malashchuk P.A., Sundukov E.YU., Fomina I.V. Transport approaches to the ports of the European and Ural Arctic. North and the market: the formation of an economic order. North and the market: the formation of an economic order 2018. № 3 (59). p.12-22. [in Russian]

[29] Kiselenko A.N. Fundamentals of the formation of a basic transport network of the European and Ural North of Russia. Transport of Russia: problems and prospects – 2017: Mater. Mezhdun. nauch.-prakt. konfer. (14-15 november 2017, St. Petersburg). p.36-40. [in Russian]

[30] Koz'movskij D.V., Sineshchuk YU.I., Artamonov V.S. Methodology for operational control to use of resources and services in automated information management system. Unified state system for the prevention and liquidation of emergency situations. Bulletin of the St. Petersburg University of the State Fire Service of the Ministry of Emergencies of Russia, 2014, №2 (2014). p. 51-59. [in Russian]

[31] Baharev T.S., Gadyshev V.A., Plotnikov YU.A. The use of geographic information systems for solving applied problems of emergency prevention. Scientific-analytical journal "Bulletin of the St. Petersburg University of the State Fire Service of the Ministry of Emergencies of Russia". 2010. T. 6. № 2. p. 12-17. [in Russian]

[32] Kuvatov V.I., Onov V.A., SHatalova N.V. Ways to improve transportation and improve vehicle safety. Problems of risk management in the technosphere. 2013. No 2. p. 96-103. [in Russian]
[33] SHatalova N.V. Road communication of the Arctic zone of the Russian Federation. Modernization and research in the transport sector. 2014. T. 1. p. 539-542. [in Russian]
[34] Concepts and Terminology - Marine Spatial Planning. UNESCO International Oceanographic Commission. URL: http://msp.ioc-unesco.org/
[35] Strategy for the development of maritime activities of the Russian Federation until 2030 URL: http://docs.cntd.ru/document/902250877 [in Russian]
[36] Strategy for the development of the Arctic zone of the Russian Federation and national security for the period until 2020. URL: http://government.ru/info/18360/ [in Russian]
[37] Fundamentals of state policy of the Russian Federation in the Arctic for the period until 2020 and further perspective. URL: http://government.ru/info/18359/ [in Russian]

INTERNATIONAL TRANSPORT CORRIDORS AS A WAY TO IMPROVE LOGISTIC PROCESSES IN MODERN CONDITIONS

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Summary

The geographical position of the Russian Federation between large centres of production and consumption of goods and services in Western Europe and Southeast Asia forms the country's significant transit potential, and makes it possible to export transportation services - high-tech goods with high added value. This will give stimulus to the mechanical engineering development, will create new hi-skilled jobs. A tool for realizing transit potential is the creation and development of an international transport corridors' (ITC) network. However, new trends in the field of circular economy, green logistics and processes and systems digitalization make it necessary to apply new principles when creating ITC and their management systems. The article discusses the main trends in the development of intermodal transport between Europe and Asia when implementing projects to create international transport corridors such as Motorways of the Seas, One Belt One Way and others. The possibilities of increasing the efficiency of logistics systems through the use of modern technological and technical solutions.

Keywords: cargo transportations, intermodal transport corridor; Euro-Asian transport routes, green logistics, transportation model

1. INTRODUCTION

Globalization processes have led to the need's awareness to find ways of transition to a new economic model. Resource depletion, climate change, negative environmental impacts are factors that raise the question of responsibility to future generations for the life on Earth preservation. Today, the linear model of the economy, based on the principle of “take-make-discard,” has been replaced by the so-called “circular economy", which has a restorative and closed nature and is based on minimizing the consumption of primary raw materials and reducing waste disposal. All this is completely correlated with such a key area of the Fourth Industrial Revolution, as the formation of environmentally friendly technical and technological systems. The complex of sustainable development principles implemented in the logistics system is called "green logistics". They envisage a reduction in the share of "environmentally unfriendly" road and air transport in favour of railways and water transport, the use of resource-saving technologies and environmentally friendly materials in logistics, the choice of logistics solutions that reduce transportation needs and a number of other measures.

Modern supply chains are global in nature, and their transport services, as a rule, cannot be provided by means of one transport type. Effective goods promotion in the supply chain requires a coordinated intercontinental transportation, long-distance transportation by land and local goods delivery, as well as terminal operations along the entire route of the goods. In transport logistics, in the foreign trade routes system and the transport process participants' activities, special attention is paid to: participants actions consistency; links minimization in the transport chain along the best route; minimum price of transportation costs. The transport logistics system implies: moving the required quantity of goods to the desired point by the optimal route for the required time and with the lowest costs. The component of transportation costs for international shipments is significant in the goods total price ready for sale. This share can be 5 - 10%, and for raw materials - 50% or more. The most effective transport agent presence, who is a single delivery operator, especially when organizing multimodal transport. The logistics system involves the use of: a single transportation rate; single transport document; consistently-central scheme of participants' interaction; high responsibility degree for the cargo. Effective functioning of global logistics systems (GLS) involves their integrated design, taking into account such factors as: transportation costs, optimal routes, environmental impact, which is particular relevance in currently. The business globalization and the transport systems of different countries integration into the world transport system taken the intensive development of international transport corridors (ITC), through which the main transit cargo flows pass. Currently, ITCs are becoming not only a tool for implementing global logistics strategies, but also a testing ground for introducing the most up-to-date logistics concepts and technologies for cargo delivery (inter- and multimodal, terminal, door-to-door, etc.).

Under the ITC is meant part of the national or international transport system, which provides significant international freight and passenger traffic between separate geographic areas, as well as includes rolling stock and stationary devices of all transport types which operating in this direction, and moreover, a set of technological, organizational and legal conditions for the implementation of these traffic. The ITC organization aims to unify nationals' legislations, harmonize the transport systems of the participating countries, create an international transport infrastructure that has common technical parameters and ensures the use of a single transport technology as the GLS basis and the national transport systems integration into the global transport system. There is an acute question about the organization of efficient modern transport corridors Europe-Asia through Russia on the modern logistics technologies basis which using the Russian transport system potential. The most advanced form of transport organization that meets the new requirements is integrated logistics intermodal technologies that allow you to integrate to take advantage of each transport type and provide the client with a high services level at affordable prices. The directions for the development of trans-European transport corridors (Trans-European transport network) and the basic principles of the future pan-European transport policy were adopted by representatives of 42 European ministries during the 2nd Pan-European Conference on Transport [1] (Crete, 1994). Additions were made at the third conference in Helsinki in 1997. As a goal, the medium and long-term coordinated development of the European transport network was formulated. During the conference in Crete, nine transport corridors were identified that should connect Western Europe with Eastern Europe, as well as European states with Asian countries. Since 1997 (3rd Pan-European Conference), the number of corridors has increased. At the same time, recommendations on the expansion of the main ITCs are presented. Currently, it is necessary to coordinate the Russian transport all types actions in to ensure optimal freight traffic and create competitive tariffs. At the same time, the projects coordination for the terminals building used by rail and road transport and new port complexes in Russia with all possible traffic participants is particular importance. One of the transport policy directions to developed countries of Europe, Asia and America is to intensify actions aimed at creating new and developing existing ITC connecting all types of land and water transport at the level of regions, countries, continents (for example, the TC "Northern and South America", trans-European: "Europe-Asia"). The transport corridors infrastructure consists of railway, road, water, and combined transport infrastructures, main and access roads, border crossings, service centres, terminals, and various structures that transport goods by certain routes.

On the Russian territory, which has a dominant role in international relations (economic, political, cultural) between the countries of Europe, Asia, and the Pacific region, there are five transport corridors: 1) the first is the Baltic zone; 2) the second - "West-East"; 3) the third is "European"; 4) seventh - "South"; 5) the ninth - "North-South." Successful transport corridors functioning is only possible due to the large organizational work being carried out, as well as the ability of transport and forwarding firms engaged in international transportation to introduce modern transportation and cargo processing technologies, use various transportation systems, "door-to-door" goods delivery, as well as modern telecommunications, tracking systems and cargo escort. Investments are needed not only to maintain transport corridors, but also to develop and extend them along cost-effective routes. In addition, the extension of the corridors 2,7,9 (about which it is written above) is supposed.

Experts of foreign companies interested in reducing transportation costs when exporting Russian raw materials suggest various projects, in particular, on the Barents Euro-Arctic Region transport corridors, which brings together a number of provinces in Sweden, Norway, Finland, and the Murmansk, Arkhangelsk Regions, Nenets Autonomous Okrug and Karelia Republic. The proposed projects most fully reflect the "junction zones" of various transport types. The transport corridors will include a sea route along the northern Russian coast and its seaports Murmansk, Arkhangelsk, Indiga; highways connecting the Murmansk region with Sweden, Norway, Finland; railway between Sweden and Finland through the Arkhangelsk region in the Urals direction; air lines at airports for international traffic in Murmansk, Arkhangelsk, Kandalaksha, as well as federal destinations in Petrozavodsk and Naryan-Mar. The Volga-Donskoy transport corridor is quite promising, because allowing uninterrupted delivery of general, container and other cargoes from Turkey, Ukraine, and other European countries, including Russia (Tuapse, Novorossiysk, Temryuk, Yeisk) to the ports of the Caspian bordering countries on "river-sea" class vessels. This transport corridor runs along the Black and Azov seas, the Tsimlyansky reservoir, as well as through the channels: The Kerch, Yenikaly, Volga-Don, Volga-Caspian. Thus, international transport corridors provide for the modern cargo carrying system operation based on the efficient transport infrastructure creation with using advanced information and logistics technologies in the transportation process (intermodal, mixed and other transportation types), compliance with legal, environmental and other requirements on the using territories. Such systems will function successfully only if innovative technical and technological solutions are used in their creation and modernization, and management will be carried out using digital technologies.

2. PROBLEM CONDITION: PROSPECTS OF INTERNATIONAL TRANSPORT CORRIDORS DEVELOPMENT AND NEW TECHNOLOGIES AS A PROGRESS DRIVER

A developed transport system is one of the necessary factors for the effective functioning and development of the state's economy and international trade. In modern conditions, when the countries' economies are connected into a single network of regional and world production, the efficient transport systems development is a prerequisite for the further mutual integration of national economies. To date, multimodal transport corridors (systems) have become widespread, focusing on the public transport general directions - rail, road, sea, pipeline, and telecommunications. At the intersection points of such corridors, communication junctions are created within which there is a preferential regime, a particularly preferential regime of foreign economic relations, economic cooperation provided by one state to another without spreading to third countries. This procedure provides high quality and variety of services, and also affects the improvement and acceleration of the passage of commercial, industrial and financial capital, strengthening information and cultural exchanges. Recently, the international cooperation role is increasing. States are interested in creating a "lightweight way" for their goods flow and services abroad. At international conferences, attention is paid to issues related to overcoming customs and tax barriers, concerted action in the establishment of port's and other transport charges. World trends in improving the goods transportation technology are now associated with the traffic flows concentration and the container traffic growth along intermodal transport corridors, which become the unified transport network basis of the 21-th century. The such a transport network formation is the main task of the Eurasian transport policy. If in Western and Central Europe, where communications are more developed, the transport corridors basic system has been largely created, then in Asia, where high rates of economic growth are maintained, this process is just beginning. The geographical position and transport infrastructure level of Russia allows it to enter the international transport markets with the quite attractive transit resources offer that meet the most modern requirements.

Transit is a kind of transport services export, it increases the Russian transport network use efficiency, stimulates its improvement. In a number of European countries (Poland, Germany, Hungary, Austria, the Netherlands, etc.), transit has been turned into budget revenues. Thus, in the Netherlands, the transit revenues share is estimated at 40% of the total income from the goods and services export. Under these conditions, the tasks of using the Russian transit potential, primarily Siberia, in combination with the tasks of developing the global transport network become one of the priorities for Russia. Moreover, the potential revenues from international transit may be comparable to income from energy exports. The Russian transit potential development will be facilitated by the fact that the possibilities of increasing the speed and reducing the cost of transportation on trans-sea shipping lines are practically exhausted, and the seaports are overloaded. Suez Canal bandwidth is close to the maximum. The magistrals container ships improvement also reached its qualitative limit. However, the possibility of high-speed rail transport, supplemented by a highways system, inland waterways and multimodal logistics centres, are just beginning to unfold. With the new computer technologies development, there is an increasing tendency to use them for the information exchange between the trade participating countries, and more and more advanced information communications are emerging. The communications industry in the leading world countries has become one of the most dynamic economy sectors. Telecommunications, including digital methods of transmitting and communicating messages, fiber-optic and space communication channels, and cellular radiotelephone links, are becoming a strategic resource. Telecommunications and computer technologies contribute to the synchronization various systems' docking of transportation, storage and redistribution of cargo flows.

2.1. Eurasian transport corridors and their role in the East-West transportation system

International transport corridors, passing through the Russian territory, appear as a connection of European and Asian transport networks. The modern ITC system in Europe concept the was initially determined by the decisions of the II and III Pan-European Conferences on Transport. The main task that was solved in this work's course was the conditions creation for the European transport networks integration and international trade during the EU expansion and the markets in Eastern Europe opening. A coordinated system of ten international transport corridors defines a network whose extreme points are Nuremberg in the west, Helsinki in the north, Thessaloniki in the south and Nizhny Novgorod in the east. All corridors have railway and road components, with the exception of corridor No. 7, which is an inland waterway along the Danube. The Pan-European transport corridors system identified the priorities for the infrastructure development and became the basis for the application of common European technical standards for roads and railways, as well as intermodal transportation routes. In addition to the corridors, taking into account the specific nature of the transport infrastructure development in the developed coastal regions, four Transport Pan-European zones were also identified: The Black Sea zone, the Barents Sea's Euro-Arctic region, the Adriatic / Ionian Sea zone and the Mediterranean zone. The Pan-European Corridor system has become the basis for ensuring connectivity between the EU transport network and the developing transport systems of Central and Eastern

Europe. The routes of three Cretan corridors partially pass through the Russian territory: the first, second, and ninth.

International transport corridor No. 1 passes through Gdansk, Warsaw, Kaliningrad, Kaunas, Riga and Tallinn. The Russian's corridor part includes roads and railway's sections. The main MTK No. 2 direction: Berlin - Warsaw - Minsk - Moscow - Nizhny Novgorod. The Pan-European transport corridor No. 9 is the longest, its length is about 3 thousand km. MTK route No. 9 passes through the territory of Russia, Finland, Lithuania, Belarus, Ukraine, Moldova, Romania, Bulgaria and Greece. Coinciding in its northern part with the MTC North-South, this corridor has great potential for growth in traffic volumes. The northern parts of corridor No. 9 (Helsinki - St. Petersburg - Moscow and Kaliningrad - Minsk - Kiev - Moscow) provide European countries with access to the Far East and the countries of the Asia-Pacific region, Central Asia, Transcaucasia, Iran and other countries of the Persian Gulf, and also Pakistan and India.

The most successful of the Eurasian corridors was the Trans-Siberian Railway, connecting Europe and Japan through the Russian Federation and having branches to Kazakhstan, China, Mongolia, the DPRK and the Korea Republic. The corridor basis was a double-track, electrified Trans-Siberian Railway. In the east, the corridor has access to the countries of the Asia-Pacific region. In the west through seaports - to European countries. 87 cities of the Russian Federation with a population of up to 15 million people gravitate toward the corridor. About 65% of coal, almost 20% of oil products and 25% of commercial timber are produced in the regions serving the main line. The main natural resources of the country, not excluding hydrocarbons, coal and forest, as well as the country's largest industry are concentrated here. The Trans-Siberian Railway advantages include the following: the container train's transit time on the journey is reduced by more than two times compared to following the sea route; low level of political risks, since up to 90% of the route passes through the Russian Federation territory; the transhipments number is reduced to a minimum, which prevents the risk of accidental damage to goods during transhipment.

The second international Eurasian corridor is the Northern Sea Route (NSR), passing in the direction from Western Europe to the Asia-Pacific region. The corridor runs through the seas of the Arctic and Pacific Oceans. It provides not only international transit between Europe and Asia, but also direct goods access from the territories of Siberia and the Far East via inland waterways - the Ob, Lena and Yenisei to foreign markets. This route has one, but a significant drawback: a short shipping period.

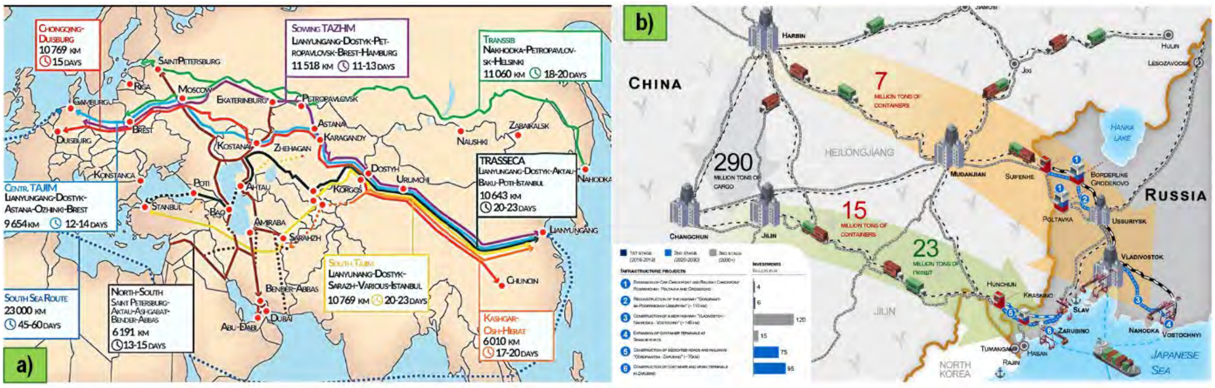

Figure 1 a) Eurasian corridors; b) ITC "Primorye 1 and 2"

The third route was the North - South transport corridor. The corridor creation initiators were Russia, India and Iran, which signed the intergovernmental Agreement on the creation of the ITC during the second Eurasian Conference on Transport in 2000. The ITC North-South formation was aimed at stimulating the development of trade and economic ties between Russia and countries The Caspian region, the Persian Gulf, South and Southeast Asia, as well as to provide transit Eurasian transport through domestic transport communications. Among the ITC North-South advantages over other routes, and in particular over the sea route through the Suez Canal, are the relatively low cost of transporting goods at a delivery high speed. ITC North-South suggests several optimal routes for transporting goods: shipping by sea through the Caspian Sea through the ports of Astrakhan, Olya, Makhachkala; direct railway communication through the Central Asia countries with subsequent access to Iranian railways at the Tejen - Serakhs border crossing; the corridor western branch of the goes from Astrakhan to Azerbaijan via Makhachkala, then with access to the Iranian railways. There is also the moving cargo option from Samur to Iran through the Armenia territory through the Julfa border station. This direction has access to other country regions, as well as to the Baltic countries, Ukraine, Belarus, and through them to the European railway network. India is more attracted by the provision of maritime transport with Iran (Mumbai - Persian Gulf ports). Iran seeks to arrange transportation via the North-South transport complex in order to enter new markets for its products, including in Northern Europe, as well as increase foreign trade with Russia, however, the current rejection of its nuclear energy program prevents Iran from implementing this project. Most Russian companies prefer to carry out shorter routes in the east-west direction along the TRACECA ITC.

2.2. Current status of intermodal transportation: problems and solutions

Intermodal transport that uses various modes, links and transport nodes is gaining more importance these days in Asia. However, there are not many studies that analyse the status of intermodal transport corridors as well as assess their performance. The paper [2] assesses infrastructure and operational status of two important intermodal transport corridors linking North-East and Central Asia namely: Korea–China–Central Asia; and Korea–China–Mongolia–Russian Federation. The corridors use maritime, road and rail modes for the transportation of goods. Based on the findings, this paper identifies issues and challenges for the development and operation of intermodal transport corridors in this regions. The authors believe that changing the methods of managing business and transport through the use of information and communication technologies by providers of logistics services and providing customers and industries at the forefront of their business could help improve transport processes.

An intermodal transportation feature, which refers to multimodal chains or networks, which include at least two transport modes, is the fact that the cargo is packed in a "container" and not processed at intermodal transfer terminals during its journey from the departure point to destination. The article [3] authors propose a new taxonomy for structuring the methods and models described in the relevant literature. According to the authors, the proposed taxonomy will be a useful tool for literature classifying and supporting further analysis, determining the main results, trends and future paths of intermodal freight transportation systems in several dimensions (for example, modes, geographical extensions, time horizons, and modelling goals). In the article [4], the authors emphasize the trend towards the progressive creation of a continental-wide integration association "Greater Eurasia" on the Eurasian Economic Union and the Shanghai Cooperation Organization basis. The general geographical feature of the countries involved in this partnership is revealed, i.e. the unique ultra-continental location of their remote landlocked territories at the world's largest distance from economical shipping routes and major global markets. It is proposed that the accelerated ITC creation of both latitudinal and meridional orientations be considered as a potential powerful tool for closer economic consolidation and interdependent economic development of the remote Greater Eurasia inland territories. The paper goal [5] was to study the interaction possibilities between intermodal terminals along the East-West and North-South ITC when developing new services / goods. The authors consider issues related to the interfacing efficiency multimodal transport, discuss the functions and role of intermodal terminals in the intermodal unit's delivery along ITC. The authors believe that the distribution activities continuation from the seaport terminal through the main terminal (hub) and further to other regions using the container trains services will provide more efficient infrastructure use (sea and domestic terminals). In addition, according to the authors, information and communication technologies will make transport services more attractive and viable.

Intermodal ties in Europe are analysed by the article authors [6]. The authors will focus on rail and barge services, since they are the of intermodal freight transport networks basis. Empirical analysis shows that the rail and the barge are complementary, from the point of view that the number of overlapping departure-destination pairs is limited, and the barge pass connections over relatively short distances, while the rail is usually used for large transport distances. The paper authors [7] also argue that intermodal rail / road transport combines the advantages of both transport modes and is often considered an effective approach to reduce the environmental impact of freight transport. However, the actual emissions of both transport modes depend on various factors such as vehicle type, traction type, fuel emission factors, payload utilization, slope profile or driving conditions. As a studies result, it was found that intermodal routes are more environmentally friendly than routes only on motorway for more than 90% of simulated traffic. Again, this value varies greatly between countries' pairs. The article [] presents a structured literature review on multimodal transportation since 2005. The authors focus on traditional strategic, tactical and operational levels of planning, presenting the corresponding models and the solution methods developed by them. The review concludes with the promising areas formulation for future research.

Intermodal transportation, which uses various transport modes, communications and transportation hubs, is now gaining more and more importance in Asia. The article [8] authors evaluate the infrastructure and operational status of two important ITC connecting Northeast and Central Asia, namely: Korea-China-Central Asia; and Korea-China-Mongolia-Russian Federation. Corridors use maritime, road and rail modes to goods transportation. Based on the data obtained, the authors identify problems and challenges for the ITC development and operation in Northeast and Central Asia. The paper [9] proposes a cooperation model in intermodal freight transport chains as multi-actor systems. In this context, the optimizing freight transportation problem is decomposed into a suitable subtasks series, each of which represents the entity operations that are associated with the matching scheme use. A discrete event model has been developed that optimizes a system based on a moving horizon to take into account the intermodal freight traffic dynamics. This structure allows for short-term / medium-term planning of intermodal freight transportation chains. The article [10] authors presented some aspects of intermodal transportation model with resource sharing, based on the cooperation methodology. The authors present a general resource sharing model and simulation transport model, as well as performance indicators for evaluating the freight network performance.

Over the past 20 years, domestic freight traffic in Australia has doubled, with an average growth of 3.5% per year. The fastest growth rate was shown by the intermodal sector, where intermodal terminals play a more prominent role. In article [11], the authors provide a trends analysis in the Australian rail freight task and assesses the existing infrastructure in throughput and efficiency terms. The article [12] goal is to analyse at a strategic level the impact on the modal separation between road, intermodal rail and intermodal inland water transport of an economic or environmental policies number. The intermodal distribution model is applied to the Belgian case to identify changes in the modal separation between a single cost minimization (operational or health-related external) and the additional road taxes introduction. The Rhine axis and adjacent trade routes south through the Alps to the Mediterranean Sea are some of the most important transport routes in Europe. Between today's ports of the North Sea such as Antwerp, Rotterdam and Amsterdam and the Ligurian coast ports in northern Italy, there are the highest concentrations of settlements and population, wealth, infrastructure and traffic flows in Europe, which now are called the Rhine-Alpine Corridor. The article [13] illustrates the approach of the INTERREG CODE24 project regarding the direct negative consequences of the corridor’s economic power, such as rising land prices, increasing pollution levels, serious problems with traffic and the further cities growth outside the main cities.

2.3. Environmental problems in cargo transportations: opportunities for moving to green logistics

In recent years, awareness of the freight transport negative externalities has increased. The article [14] presents the basic principles and overview of the last times studies on the freight transport "greening" using Operational Research based planning methods. Particular attention is paid to the studies that have been described for two widely used transporting goods methods around the globe, namely road transport (including city and electric vehicles) and sea transport, although other methods are also briefly discussed. Experts, proposing solutions aimed at reducing air emissions, usually propose the replacement of road transport by rail. However, in many countries and for many companies around the world, a full transition to rail goods transportation is not possible due to the lack of accessible railway infrastructure or high investment costs. Given this fact, the authors of [15] assess the potential of intermodal operations in road and rail transport as a strategy to reduce air emissions and, thus, help mitigate the effects of climate change around the world. The results show that intermodal road and rail transport will reduce emissions to 77.4%, increase fuel efficiency to 43.48% and be 80% cheaper than transportation by road vehicles alone, which is a viable mitigation strategy climate change impacts.

In article [16], potential routes for supplying natural and renewable natural gas (RNG), as well as natural gas vehicles (NGVs), were selected and evaluated in terms well-to-wheel energy expended, greenhouse gas (GHG) emissions, and regulated (air pollutant) emissions The results show that the use of compressed and liquefied natural gas (LNG) compared to conventional fuels for vehicles of all classes has the reducing GHG emissions by 15–27% per kilometre. The effect becomes large, 81–211%, when compressed and liquefied RNG is used instead. In marine applications, the use of LNG and RNG instead of marine fuel with a low sulphur content reduces PM emissions by 60–100% SOx and 90–96%. The methane intake of 1% of the allocated LNG passenger vessel leads to an average increase in net GHG emissions of 8.5%. The life cycle (LC) of liquefied natural gas (LNG) and compressed natural gas (CNG) as a fuel for heavy trucks taking into account methane leaks in LNG supply chains is analysed by the authors of [17] also. LC analysis shows that heavy trucks running on LNG and CNG will reduce greenhouse gas emissions by 11.17% and 5.18%, respectively, compared to diesel. Greenhouse gas emissions from the fuel use are the main component and comprise 71 ~ 78% of total LC greenhouse gas emissions.

Complexity in transport networks necessitates an immediate response to changing dynamics and uncertainties in upstream operations, where several modes of transport are often available but rarely used together. The paper [18] proposes a strategic transport planning model with using the intermodal transport system of the entire network. Traffic flow estimation is performed by kernel-based reference vector mechanisms, while mixed integer programming (MIP) is used to optimize schedules for an intermodal transport network taking into account various costs and network capacity additional limitations. A land use regression model was applied in research [19] to Dublin city for provide a PM10 forecast at the route level throughout the city. The authors found that the route choice based on the air pollution dose depended on the time interval and congestion degree, as well as on many other factors that influenced the emissions dispersion, but not necessarily on the speed or amount of emissions per se. Therefore, the optimal route choice for the lowest dose was significantly different from other cost factors. RoRo transportation, which now represents the marine segment, can easily become part of the intermodal transport system, since the cargo "rolls" to and from the ship and does not need to be loaded in ports. The authors of [20] study the operation of RoRo delivery services in Northern Europe, and focuses on the services set which chartered by a large shipper, whose requirements have a great influence on the services' structure, potentially affect the departures frequency, and even to specific vessels use. The results of this document may lead to the development of sustainable intermodal transport chains

Oil pollution in the World ocean is mainly caused by operational discharges from tankers (the predominant oil is discharged during refinement operations). The article [21] authors emphasize that these discharges lead to more than 2 million oil tons that are dumped annually, which is comparable to one catastrophe full tanker a per week. Oil spills monitoring over the Kazakhstan sector of the Caspian Sea show that it can be confidently stated that the oil pollution main source is shipping (that confirmed by the spots shape analysis and accumulations along shipping routes). The most polluted area its southern part, where shipping is more intensive in the direction of Aktau - Baku (Azerbaijan), Aktau - Turkmenbashi (Turkmenistan) and Aktau - Neka (Iran). In the northern Caspian Sea part, it was found that a small spills number could be caused by fishing and marine activities in the Kashagan oil field development area.

The maritime transport development problems in Russia are caused by the lag in the inland seaports development. The roadstead complex building in the Petropavlovsk-Kamchatsky seaport is a prospect for the marine infrastructure development. The article [22] authors presented a promising project with the resulting cash flows and criteria for calculating its effectiveness. In order to take into account, the main risks associated with the raid complex building, a geological, engineering, construction, force majeure, sensitivity analysis to variable parameters was carried out.

The article [23] examines the land bridges role as a factor in reducing continentality, using the Russia and Canada cases as an example. An example of the TransCanada railway, as well as the Trans-Siberian railway and the central OBOR route, show that, thanks to relatively cheap tariffs, they will improve the transport and geographical position of the internal regions. However, they cannot completely overcome these regions continental nature and compete on equal terms with the regions facing the sea or inland waterways accessible for maritime navigation (St. Lawrence and the Great Lakes, Sea Route, Yangtze River, Xi River). At the same time, the cross-border transport infrastructure development linking neigh-boring internal regions contributes to the intensification of trade and economic ties between them.

3. RESULTS AND DISCUSSIONS

Optimization of supply chain management is current interest for industries such as the automotive industry, the aerospace industry, etc., since production processes are expensive, which is directly related to the logistics system quality. The globalization processes are forcing the management of international companies to realize the improvement of the logistics structure in accordance with the market needs, in order to maintain competitiveness and reduce costs. High transportation costs complicate the complex industries creation. Therefore, in such industries it is necessary to improve management methods to minimize costs associated with the transportation of raw materials and goods.

3.1. Case Study: Organization of the Automotive Spare Parts Supply

For organization of effective spare parts delivery, the following tasks should be solved: 1) factors identification affecting the final managerial decision, 2) transportation mode selection, 3) consideration of all possible alternatives to transportation routes, 4) possible risks identification which associated to proposed options, 5) multicriteria evaluation of each alternative and making the best managerial decision. Today, globalization of automotive markets, the emergence of assembly plants in different countries and creation of the branded service networks (BSN) lengthen the supply chains. The intermodal transportation applying and decision support systems (DSS) creation will help optimize processes related to supply chain management.

The Public Corporation “KAMAZ” [24] has been selected for a case study, because it is the largest automobile corporation of Russia and is one among the top 10 heavy duty truck manufacturers of the world. It has a wide network of authorized dealers, outlets, shops and warehouses across Russia, Commonwealth of Independent States (CIS) and different parts of the world with about 50,000 employees. To ensure effective work with dealers, PC “KAMAZ” a logistics system been created. Its tasks are: improvement of supply chain management, increase in the share of suppliers of “A” category to 80%, long-term contracts, logistics automation, end-to-end supply chain, development of new lines of business (such as Internet sales, telematics, “product as a service”).

On the map (Fig. 2a), the plant-manufacturer PC "KAMAZ", as well as some points of its spare parts' sales and automobiles' service are marked. PC "KAMAZ" is situated in Naberezhnye Chelny city, Volga Federal District. In this region, in December 2015, the first stage of the Sviyazhsky Interregional Multimodal Logistics Center was launched, which located on the intersection of the two main Euro-Asian transport routes "East – West" and "North – South" and that it has access to the federal transport mains of rail, water, motor transport. The Sviyazhsky terminal is able to become a major trans-shipment point for export-import cargo for all regions of the Volga Federal District, as well as a nodal river port for the transport of goods along international transport corridors.

Since transportation of automotive spare parts is a very complex process, involving many areas of technology, management, science, etc. that is also influenced by a lot of different factors, decisions are often made under conditions of incomplete information. In order to identify all the significant factors, the complete, relevant and adequate information, as well as the application of tools and methods of its processing and analysis is needed. Multicriteria analysis methods, OLAP-technologies, simulation, as well as the elements of situational management have to be used to make the final managerial decision. In addition, since any error in supply chain management can lead to financial, time and other losses, methods of risk analysis and management have to be used.

It is rather difficult to describe the supply chain management system solely by analytical methods due to the large number of elements, parameters and factors affecting it. Moreover, external factors, input processes parameters and system characteristics themselves have a stochastic nature. Therefore, the system's behavior predicting results by analytical functions may be completely unreliable. In contrast, simulation models make it possible to take into account the stochastic behavior of such parameters as demand, the vehicles fleet reliability, loading-unloading time, travel time, supply failures. Also, on this model, you can explore a few valid solutions.

The delivery routes are constructed and analyzed using simulation models, where the input information is statistics of failures of certain systems and units under various operating conditions. These models are based on other models that forecast spare parts demand in various regions. All models are built with the use of the special simulation software AnyLogic. The proposed model for spare parts delivery planning includes such agents as "Main" (includes the GIS-connected map with the DSCs, terminals and possible routes marked on it), "Vehicle" (includes all vehicles' characteristics influencing on the spare parts failures and represented by the state-chart (Fig. 2)), "Dealer and Service Center" (is represented by a state-chart connected to the vehicles' health and the data on the spare parts existence in the warehouse), "Transportation process" (is represented by a model flowchart (Fig. 38)).

As the first stage, the simulation model to predict spare parts demand was built. It is based on the analysis of the failure statistics of vehicles KAMAZ in different exploitation regions in different seasons of the year. The information on the names of spare parts, assemblies and units that were needed in every dealer and service center (DSC) during last years in different seasons was used as the input information to predict the demand in spare parts. The model's validation and verification was made on the basis of data gained from the PC "KAMAZ".

Since in different situations the decision making person may have different objective functions, the proposed model allows to compare different options in different dimensions. It can be: delivery time minimization:

$$T = T_l + T_t + T_d + T_u \rightarrow \min, \quad (1)$$

where T_l – loading time, T_t – transportation time, T_d – delays, T_u – unloading time; costs minimization:

$$C = C_{l\text{-}u} + C_f + C_s + C_d + C_e + C_o \rightarrow \min, \quad (2)$$

where C_l – costs of loading/unloading operations, C_f – costs of the fuel, C_f – costs of the vehicles' maintenance, C_d – costs of the drivers' salary, C_e – costs of the negative impact on the environment, C_o – organizational costs; air pollution minimization

$$P = \sum_{i=1}^{n} P_i \rightarrow \min, \quad (3)$$

where i – pollutions of the transport mode that is used for transportation normalized to the distance.

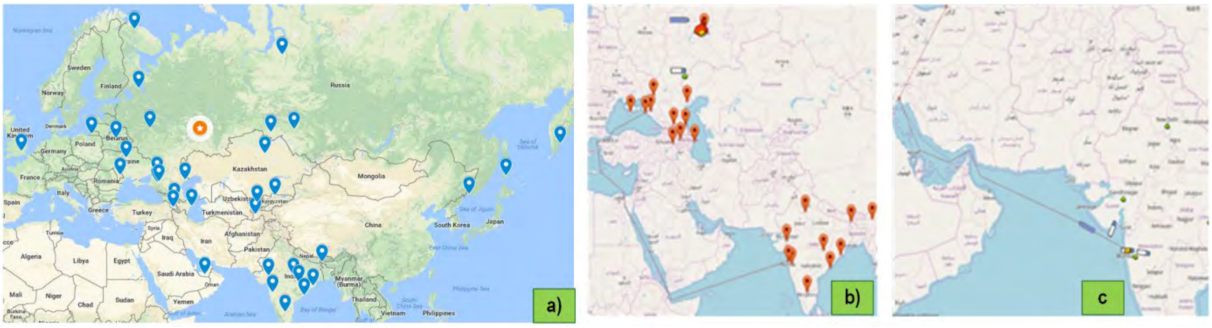

Figure 2 a) Location of some authorized dealers and warehouses of PC "KAMAZ; b), c) Model's animation

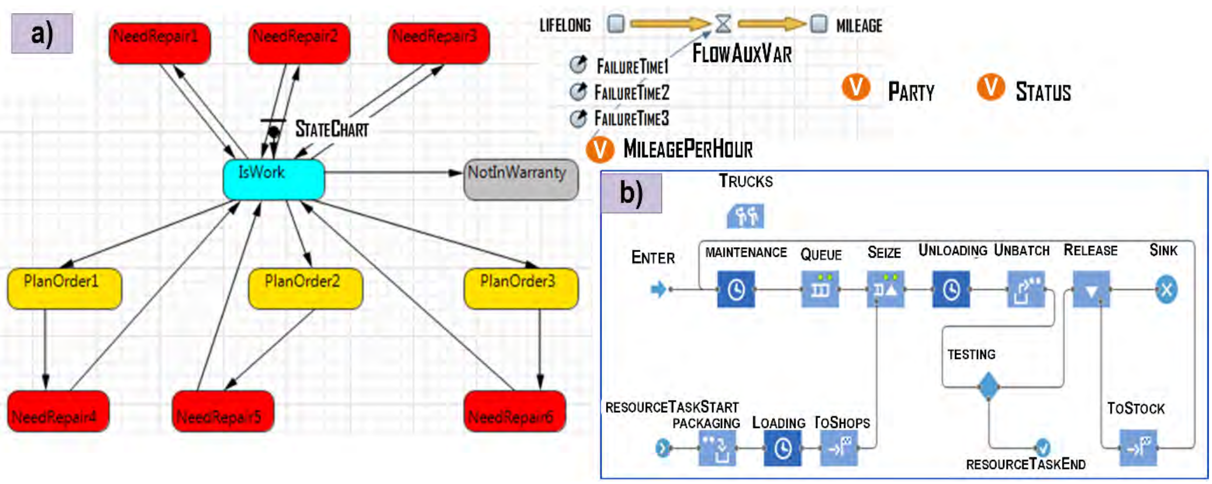

Figure 3 a) Agent "Vehicle" represented by the statechart to predict spare parts demand; b) Agent "Transportation" represented by the flowchart to model the spare parts delivery

The next step was to analyze the possible directions of improving the PC "KAMAZ" spare parts delivery. Today, delivery of spare parts to the Central part of Russia and to the regions, through which the "North – South" international transport corridor passes, is carried out either by road, or rail transport.

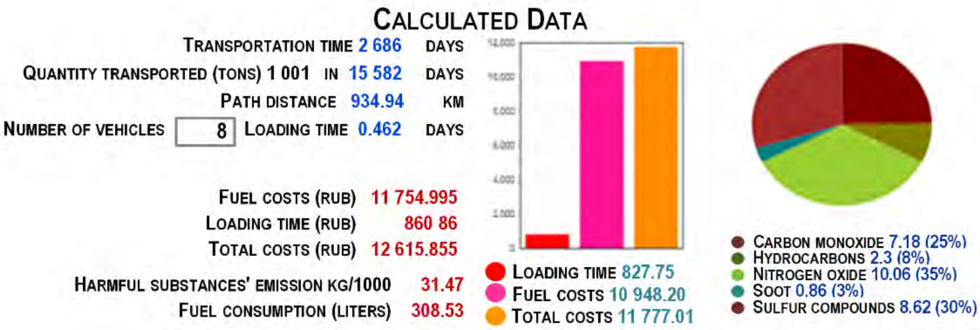

Figure 4 Representation of the modelling results

As it concerns abroad transportations, due to the fact that Russia has land borders and developed road and rail communication with Azerbaijan, Turkmenistan and Kazakhstan, deliveries are carried out by land transport modes. However, given the development of seaports in the Caspian basin, we propose to consider the following route: delivery of large shipments of spare parts by land transport to the terminal in the Caspian region, where to break them up into smaller units and to deliver small lots to the nearby Russian cities and to Georgia by trucks, and to Azerbaijan, Turkmenistan, Uzbekistan and Kazakhstan, as well as to India by sea when the New Silk Road will be finished. The other example of remote and hard-to-reach Russian cities are Magadan, Yuzhno Sakhalinsk, Petropavlovsk-Kamchatskiy, where the land transport routes are poorly developed. Therefore, it is necessary to consider the option of spare parts delivery via the Northern Sea Route. The model's animation for the case of the delivery to Indian DSC is presented on the Fig. 1 b, c and the example of calculated data is shown on the Fig. 4.

3.2. Mathematical and Simulation models to vehicles' selection when cargo delivery

In that event that a goods delivery route is selected and there are route sectors, where road transport is used, then in order to comply with the green logistics principles, management decisions are needed to optimize the existing chain. In this case, reducing the transport negative impact on the environment is achieved in various ways: choosing environmentally friendly fuels, optimizing vehicle loading, eliminating empty runs, choosing a delivery mode, etc. For such an analysis, modeling is also well suited. Based on the classical economic and mathematical model of the transportation problem, we can formulate the following simplest mathematical model for the selection of the vehicles' fleet for cargo delivery. The goal function will minimize the transporting goods summary cost:

$$Z = \sum_{k \in M} \sum_{j \in U} C_j^k \cdot X_j^k \rightarrow \min \tag{4}$$

where C^k_j - the goods transportation cost by vehicle *k* to destination *j*; *k* - list vehicle number in the fleet; *M* is a fleet size; *U* is a lot of destinations point.

$X_j^k \in \{0,1\}$ – this is a boolean variable that determines whether vehicle k will be transported to destination *j* or not:

$$X_j^k = \begin{cases} 1, \text{if the trip is carried out} \\ 0, \text{if the trip is not carried out} \end{cases} \tag{5}$$

$$\gamma_{carr} \geq 0.8 \tag{6}$$

where γ_{carr} – load capacity.

The solution of this problem is a solution of the transportation problem, where we have a matrix, where the rows correspond to the interchangeable rolling stock types of the same body type, but with a different capacity, and the columns will correspond to delivery points (orders). Then the goods delivering cost from row *i* to column *j* will correspond to the transporting estimated cost the freight unit on vehicle *i* to destination *j*. The difference from the classical transport problem is that the lines will not correspond to the capabilities of the manufacturer, but the maximum carrying capacity of the vehicle type *i*, available in the enterprise. If the available capacity is less than the required, then a fictitious carrier (or several such carriers) is introduced from which it is possible to rent vehicles.

The AnyLogic software was chosen as the simulation modeling environment6 where the agent modeling principle is implemented. Thus, the proposed model for supply management in the logistics chain includes such agents as "Main" (includes a GIS-linked map with the production site, central warehouse and stores, Fig. 5), "Central warehouse" (A block diagram is presented, including assigning a vehicle to an incoming order, loading, delivery of goods, unloading and returning the vehicle to the central warehouse, Fig. 6c), "Truck" and "Airplane" (represented by state diagrams, Fig. 6 a,b), "Shop", "Factory", "Order".

Figure 5 Simulation model: Agent "Main" view

During the optimization experiment (Fig. 6 d), the delivering goods total cost of was minimized by changing the number of trucks and loading them. Its showed that 12 trucks are needed for the smooth logistics system operation. To ensure a given level of goods assortment in a store in Naberezhnye Chelny, it is necessary to deliver 8,000 goods units from a central warehouse in Moscow with a 26.6 days' interval.

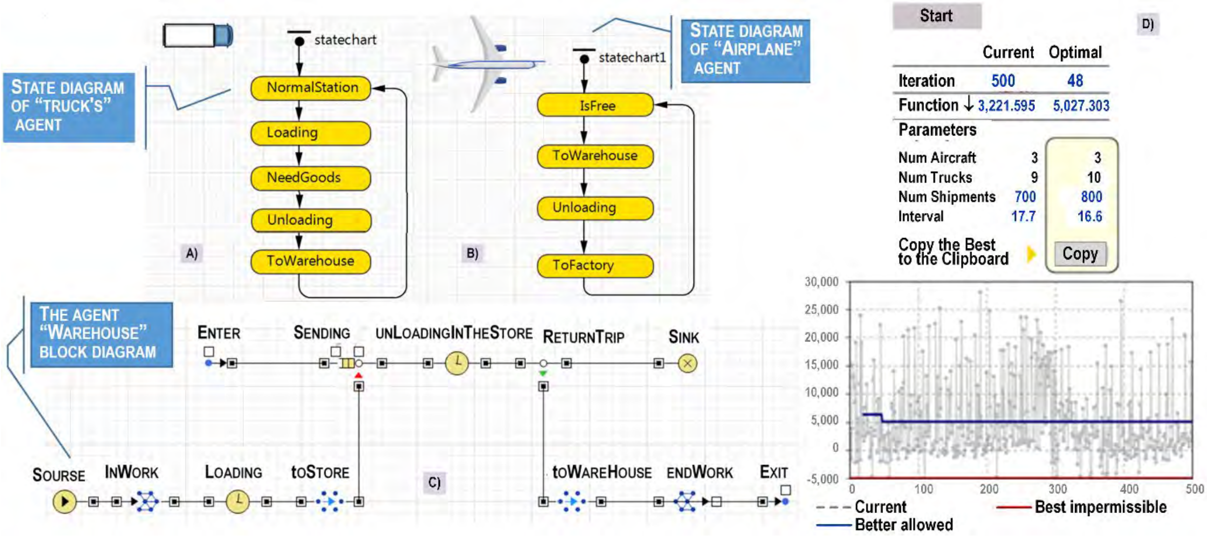

Figure 6 A) – C) Agent model; D) Supply Chain Optimization

4. CONCLUSION

In modern conditions, the importance of international transport corridors and their functioning quality are growing. The most important condition for the formation of modern transport infrastructure is its digitalization. Many transport companies have developed digitalization roadmaps and selected the most important technology tools. Digitalization of the transport industry in Russia, which is a key element in the ITC architecture between Europe and Asia, is one of the state priorities. Its decision will determine the economy's competitiveness and the country's transit potential development. In June 2019, at the annual IT Breakfast "Digital Economy Transformation. International and Russian experience in the transport sector digitization", held at the St. Petersburg International Economic Forum, experts from the European

Commission and the UN participating in the event spoke about global trends in the digital technologies in transport development and the need for international cooperation. The main emphasis, in their opinion, needs to be done on training personnel, increasing public confidence and developing common standards to transport and logistics digitalization for all countries.

Digital transport corridors, highlighted as one of the digital agenda priorities to Eurasian Economic Union (EAEU), have become the key topic of the 25th TIBO-2018 international forum on information and communication technologies in Minsk [25]. According to the member of the Board (Minister) for Internal Markets, Informatization, Information and Communication Technologies of the Eurasian Economic Commission (ECE) Karine Minasyan, the intersectoral projects nature on digital transport systems requires the combined efforts of various economy sectors representatives. The introduction of digital technologies in transport, logistics, freight transportation administration and public administration will help significantly reduce the "transport shoulder" and increase transport efficiency. Automation of legally significant electronic accompanying documents formation, including through the paperless smart- contracts award, reduces time and reduces transportation cost.

REFERENCES

[1] Status of the Pan-European Transport Corridors and Transport Areas. Corridor Status Report. Prepared by the TINA Office Vienna, December 1998/ 106 p. URL: http://aei.pitt.edu/39350/1/A4030.pdf

[2] Madan B. Regmi, Shinya Hanaoka. Assessment of intermodal transport corridors: Cases from North-East and Central Asia. Research in Transportation Business & Management 5 (2012) 27–37

[3] Crainic T.G., Perboli G., Rosano M. Simulation of intermodal freight transportation systems: a taxonomy. European Journal of Operational Research 270 (2018) 401–418

[4] Bezrukov L.A. The Geographical Implications of the Creation of "Greater Eurasia". Geography and Natural Resources, 2018, Vol. 39, No. 4, pp. 287-295.

[5] Raimondas Š., Nijolė B. Research on Intermodal Terminal Interaction in International Transport Corridors. Procedia Engineering 187 (2017) 281 – 288

[6] de Langen P.W., Lases Figueroa D.M., van Donselaar K.H., Bozuwa J. Intermodal connectivity in Europe, an empirical exploration. Research in Transportation Business & Management 23 (2017) 3–11

[7] Heinold Arne, Meisel Frank. Emission rates of intermodal rail/road and road-only transportation in Europe: A comprehensive simulation study. Transportation Research Part D 65 (2018) 421–437

[8] Madan B. Regmi, Shinya Hanaoka Assessment of intermodal transport corridors: Cases from North-East and Central Asia. Research in Transportation Business & Management 5 (2012) 27–37

[9] Di Febbraro A., Sacco N., Saeednia M. An agent-based framework for cooperative planning of intermodal freight transport chains. Transportation Research Part C 64 (2016) 72–85

[10] Furtado P. Frayret J.-M. Proposal Sustainability Assessment of Resource Sharing in Intermodal Freight Transport with Agent-based Simulation. IFAC-PapersOnLine 48-3 (2015) 436–441

[11] Ghaderia H., Cahoon S., Nguyen H.-O. The role of intermodal terminals in the development of non-bulk rail freight market in Australia. Case Studies on Transport Policy 4 (2016) 294–305

[12] Mostert M., Carisb A., Limbourg S.. Road and intermodal transport performance: the impact of operational costs and air pollution external costs. Research in Transportation Business & Management 23 (2017) 75–85

[13] Drewello H., Scholl B. (2016) Introduction. In: Drewello H., Scholl B. (eds) Integrated Spatial and Transport Infrastructure Development. Contributions to Economics. Springer, Cham pp 1-7

[14] Bekta T., Ehmke J.F., Psaraftis H.N., Puching J. The role of operational research in green freight transportation. European Journal of Operational Research 274 (2019) 807–823

[15] Torres J.de Pintoa M., Mistageb O., Bilottac P., Helmersd E. Road-rail intermodal freight transport as a strategy for climate change mitigation. Environmental Development 25 (2018) 100–110

[16] Hagos D.A., Ahlgren E.O. Well-to-wheel assessment of natural gas vehicles and their fuel supply infrastructures – Perspectives on gas in transport in Denmark. Transportation Research P. D 65 (2018) 14–35

[17] Zhiyia Y., Xunmina O. Life Cycle Analysis on Liquefied Natural Gas and Compressed Natural Gas in Heavy-duty Trucks with Methane Leakage Emphasized. Energy Procedia 158 (2019) 3652–3657

[18] Bhattacharya A., Kumar S.A., Tiwari M.K, Talluri S.. An intermodal freight transport system for optimal supply chain logistics. Transportation Research Part C 38 (2014) 73–84

[19] Alama M.S., Perugub H., McNabola A.. A comparison of route-choice navigation across air pollution exposure, CO2 emission and traditional travel cost factors. Transportation Research Part D 65 (2018) 82–100

[20] Anastasia Christodoulou, Zeeshan Raza and Johan Woxenius. The Integration of RoRo Shipping in Sustainable Intermodal Transport Chains: The Case of a North European RoRo Service. Sustainability 2019, 11, 2422

[21] Holstein, A., Kappas, M., Propastin, P. et al. Oil spill detection in the Kazakhstan sector of the Caspian Sea with the help of ENVISAT ASAR data. Environmental Earth Sciences (2018) 77:198.

[22] Miroshnikova T. and Taskaeva N. Creation of a raid complex as a promising direction for the development of the seaport of Petropavlovsk-Kamchatsky. MATEC Web of Conf. 239, 03007 (2018). TransSiberia 2018

[23] Lomakina A.I. Transcontinental bridges VS continentality: the case of Russia and Canada. 2018 IOP Conference Series: Earth and Environmental Science. 190 012059

[24] KAMAZ, official website, https://kamaz.ru/en/about/development/mission/, last accessed 2018/10/05.

[25] XXVI international ICT forum URL: https://tibo.by/en/

PRECISE CONTROL OF THE UNMANNED SURFACE SHIP - SELECTED PROBLEMS

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Summary

The research presentation considered the application of fuzzy logic to design an autopilot for precision control of unmanned surface ship (USV). In the process of USV motion control on the given trajectory, independently functioning proportional-derivatives PD controllers of the PD type were used. They are used to generate control signals for ship's actuators. Parameters of fuzzy controllers are tuned by using the algorithms developed by the author. Simulation studies were carried out to confirm the effectiveness of precision control. The developed control algorithm was also used to regulate the movement of a small surface ship called "Edredon". USV "Edredon" was built at the Polish Naval Academy. "Edredon", the first Polish unmanned navigable ship (USV), was developed by a group of scientists from the Naval Academy in Gdynia. Researchers were supported by military and civilian specialists responsible for safe navigation and environmental protection. The subject of this article is an attempt to solve control problems commonly found in the automatic control systems of the USV. Control fuzzy systems are finding wide practical applications to making decision to control and modeling of the complex of control systems of USV. This paper explores fuzzy logic and it helps navigators in making the decision in the process of steering the USV. Fuzzy logic methods provides an intuitive way to design function blocks for intelligent control systems of the USV motion. This paper consists of the following sections. It starts with a brief description of dynamical and kinematical equations of the USV's motion and their frames of reference. Then a fuzzy control law and a control algorithm are presented. Next some simulation results are provided. Conclusions are given in the last section.

Keywords: - Unmanned Surface Vessel, Control of USV, Autopilot, Fuzzy control, Artificial intelligence, Computer control.

1. INTRODUCTION

Unmanned surface vehicle – USV, was built in Poland and called - "EDREDON". The USV was developed by researchers from the Naval Academy in Gdynia and Gdansk University of Technology and was made in the years 2009-2011 as a result of research project: "Unmanned swimming platforms for the protection of national sea services". The structure of USV is based on the rigid hull of a hybrid boat (RIB - Rigid Inflatable Boat) made from fibreglass and rubberized fabric – ORCA. During this project was designed and built USV

"EDREDON" - remotely controlled, universal, unmanned surface platform, equipped with devices and sensors allowing flexible implementation of various tasks. The platform's versatility is ensured by a modular construction allowing vast scope of application and change of purpose of use. In military applications, the vehicle's extension is realized through the installation of additional modules, such as a remotely controlled machine-gun, depth charge launcher, an unmanned underwater vehicle, a disposable underwater vehicle against floating mines, search light, towed sonar, etc. The vehicle may also be equipped with special sensors measuring for example radioactive, chemical and biological contamination of the marine environment (including port basins), etc.

The continuation of above program was next research project realized in the years 2010 – 2012: "Integrated system of planning the parametric protection and the monitoring of sea harbours and critical objects, based on autonomous unmanned maritime vehicles". The leader of this project was the Polish-Japanese Institute of Information Technology and its coexecutors the Polish Naval Academy and the company SPRINT S.A. The task of this project was to ensure full autonomy of the vehicle and extend the area of on-going tasks. Scientific supervision of both projects was conducted by Prof. Z. Kitowski.

Figure 1 The unmanned surface vessel 'Edredon' during the sea trials

Source: R&D project No. 0 R00 0004 07 documentation

As a result of 2 projects was constructed the "technology demonstrator", which now is not a final product.

The vehicle based on the Sportis company's RIB S 5700 and is equipped with Yanmar ZT350 132kW/180 hp sterndrive engine. The vehicle has several autonomous functions and abililty to return to base upon loss of communications. "EDREDON" is operated by a two-man crew in a containerized control station.

1.1. Model of the control system

Fuzzy logic finds wide practical applications. First of all to making decision ranging from soft regulatory control in consumer products to accurate control and modeling of complex nonlinear systems of ship. This paper showed a possibility of using a fuzzy logic environment as a method making-decision to solve the problem related to determining an optimal ship trajectory in low speed motion. It is possible to effectively solve tasks of determining a trajectory movement of a ship as a multistage decision-making process in a fuzzy environment [2, 11, 14]. A officer-navigator operates the ship with according to his individual assessment of the risk of collision, economical effects etc. Usually, make a decision of control of the ship is an individual decision the helmsman, which depends on his knowledge and experience [1, 4, 7].

Basic modules of the proposed control system are depicted in Fig. 2. The precise control system computes command signals τ_d comparing desired vehicle's position x_d, orientation and velocities with their current estimates. Corresponding values of propellers thrust *f* are calculated in the thrust distribution module and transmitted as control input to the propulsion system. The propulsion system generates a control signal τ consists of thrust forces actuators of the ship. On the body of the ship are acting a sea disturbances z. The precise control system adjustments are modified by a position and velocity data [3, 7, 8].

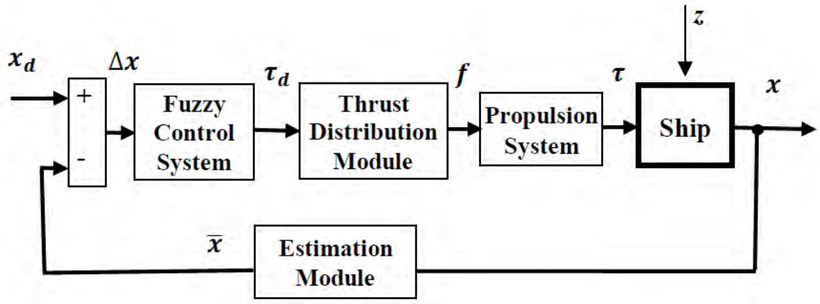


Figure 2 The precise control system of the ship: $x_d = (\eta_d, V_d)$ – desired position; $x = (\eta, V)$ – real position

1.2. Reference frames of the USV

In this article two reference frames are used for description a precise control. They are the Earth fixed reference frame $O_nx_ny_n$ and the Body reference frame $O_bx_{Ob}y_{Ob}$ (Fig. 3).

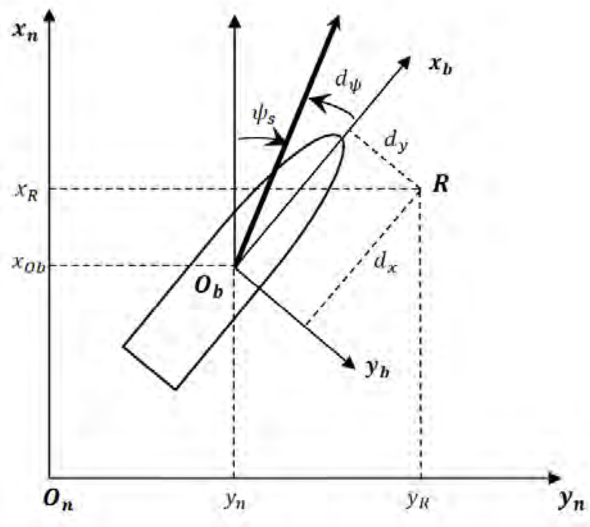


Figure 3 Reference frames. *R* – reference point in USV's trajectory - required position of the ship; d_x – position deviation in *x*-axis of *b*-frame, d_y – position deviation in *y*-axis of *b*-frame; Ψ_s – angle of heading (course of a USV); d_Ψ – course deviation

Earth fixed reference frame, $O_nx_ny_n$ or *n*-frame - this coordinate system is defined with respect to the Earth reference ellipsoid. In this coordinate system the x-axis points towards true North, and the y-axis points towards East. Body reference frame, $O_bx_{Ob}y_{Ob}$ or *b*-frame - this is the moving coordinate system which is fixed to the body of a USV. The origin O_b of the coordinate system is chosen to coincide with the center of gravity

(*CG*). It is assumed that point *CG* is in the principal plane of symmetry of the USV. The axes are defined as *x*- the longitudinal axis, and *y* - the transversal axis - Fig. 3 [11].

The position of the ship is determined by GPS in the n-frame and other control signals (eg. deviations) are measured in the b-frame. The coordinate and velocity transfer functions between these reference frames are the following:

$$[x_b, y_b, \psi_b]^T = R_b^n[x_n - x_{Ob}, \quad y_n - y_{Ob}, 0]^T$$
$$[u, v, r]^T = R_b^n[\dot{x}_n, \dot{y}_n, r]^T \tag{1}$$

where the rotation matrix is equal to:

$$R_b^n = \begin{bmatrix} cos\psi & -sin\psi & 0 \\ sin\psi & cos\psi & 1 \\ 0 & 0 & 1 \end{bmatrix}^{-1}$$

Reference point *R* - is a point, coordinates of which define the required position of the hull geometric center *CG*. Position of the ship motion is controlled by relevant changes of coordinates of this point with respect to *CG* point.

2. EQUATIONS OF THE USV MOTION

Usually, it is assumed that the following three vectors describe a motion of a ship of six degrees of freedom (DOF) [3, 5, 9]:

$$\boldsymbol{\eta} = [x, y, z, \varphi, \theta, \psi]^T$$
$$\boldsymbol{V} = [u, v, w, p, q, r]^T \tag{2}$$
$$\boldsymbol{\tau} = [X, Y, Z, K, M, N]^T$$

where:
η – vector of position and orientation in *n*-frame;
x, y, z – coordinates of position;
φ, θ, ϕ – coordinates of orientation (Euler's angles);
V - vector of linear and angular velocities in the *b*-frame;
u, v, w – linear velocities along longitudinal, transversal and vertical axes;
p, q, r – angular velocities about longitudinal, transversal and vertical axes;
$\boldsymbol{\tau}$ – vector of forces and moments acting on the vehicle in the *b*-frame;
X, Y, Z – forces acting along a longitudinal, a transversal and vertical axes;
K, M, N – moments acting around a longitudinal, a transversal and a vertical axes.

The dynamical and kinematical equations of motion in b-frame can be expressed as [3, 9]:

$$\boldsymbol{M}\dot{v} + \boldsymbol{C}(v)v + \boldsymbol{D}(v)v + \boldsymbol{g}(\eta) = \boldsymbol{\tau}$$
$$\dot{\eta} = \boldsymbol{J}(\eta)v \tag{3}$$

where:
M – inertia matrix (including added mass);
C(v) – matrix of Coriolis and centripetal terms (including added mass);
D(v) – hydrodynamic damping and lift matrix;
g(η) – vector of gravitational forces and moments;
J(η) – velocity transformation matrix between *n*- and *b*- frames.

3. FUZZY CONTROL LAW

In this article is adopted a fuzzy proportional derivative controller (*FPD*), who working in configuration in Fig. 4. This controller has been used for control of the ship's motion [2, 7, 8, 10].

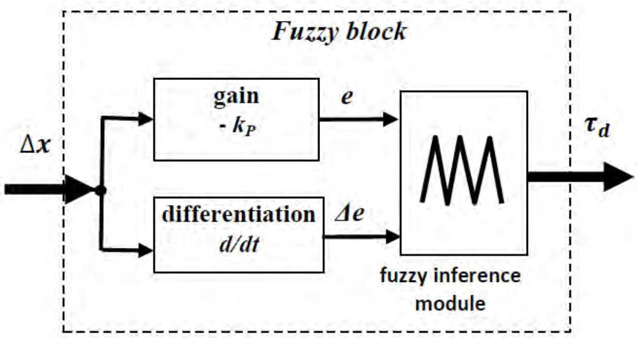
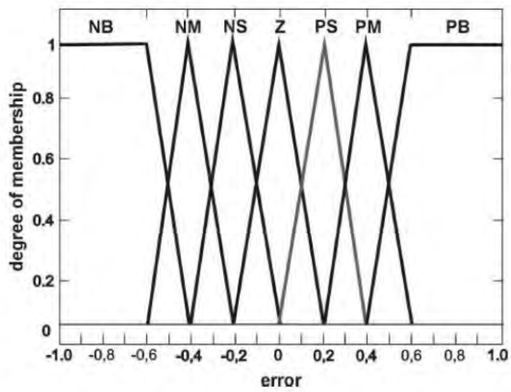
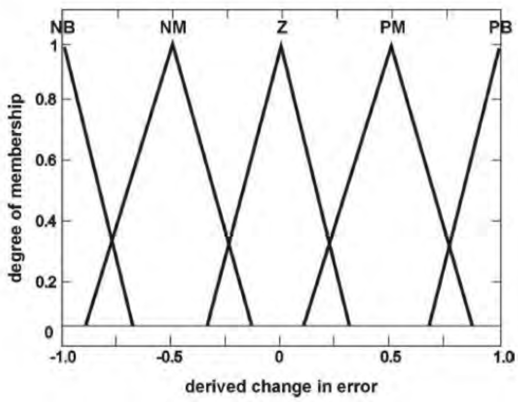


Figure 4 Fuzzy controller in the precise control system of the ship $\Delta x = x_d - \bar{x}$.

where
$x_d = (\eta_d, V_d)$ – desired position of a USV;
$\bar{x} = (\bar{\eta}, \bar{V})$ – real position of a USV after estimation

Membership functions of fuzzy sets of input variables: an error signal e and a derived change in error -Δe as well as an output variable: command signal τ_d are shown respectively in Fig. 5, where the following notation is used: N – negative, Z – zero, P – positive, S – small, M – medium and B – big.





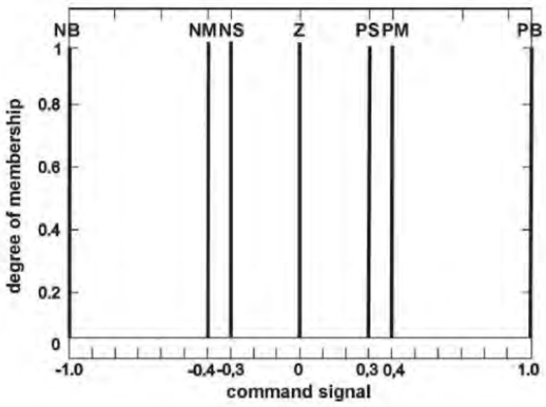


Figure 5 Membership functions for fuzzy sets used in precise control of ship.

Presented in Table 1 rules, taken from the Mac Vicar-Whelan's standard base of rules, have been chosen as the control ones [2, 8].

Table 1. Base of rules in fuzzy control of the ship.

		error signal - *e*				
		NB	*NM*	*Z*	*PM*	*PB*
derived change in error - *Δe*	*N*	NB	NM	NS	Z	PS
	Z	NM	NS	Z	PS	PM
	B	NS	Z	PS	PM	PB
		command signal - τ_d				

To designing of the control system the fuzzy proportional derivative (FPD) controller is adopted from [2, 8, 14]. This has been used fuzzy controller working in a configuration presented in Fig. 4.

Membership functions of fuzzy sets of input variables are: error signal $e(t) = \eta_d(t) - \eta_t$ and derived change in error $\Delta e(t) = \eta(t) - \eta(t-1)$ and a output command signal - $\tau_d(t)$. Inputs signals are represents by triangular-shaped membership functions and output signal by a singleton type of membership function. The notation is taken as given above: N – negative, Z – zero, P – positive, S – small, M – medium and B – big .

The output control signals from the fuzzy controller τ_d have the form of set pulses. The control signals from fuzzy controller τ_d have the form of set pulses. The magnitude of control signal is changed in steps and depends of duration this signal. Time of duration and magnitude of signals are adjusted continuously and is subject to stringent control. We make use of such of the control signals so a relatively simple and effective control algorithm is obtained. Method in action of this control algorithm is similar to steering executed by the helmsman of the ship. It is relatively resistant to the ship dynamics changes and external disturbances. The parameters of the control signals can be defined in the following way [11]:

$$\begin{gathered}\Delta t = f_{\Delta t}(\varepsilon_\eta, \nu) \\ \bar{F} = f_{\bar{F}}(\varepsilon_\eta, \nu) \\ \dot{\varepsilon}_\eta = f_d(m, \varepsilon_\eta, \tau_z, F) \\ \nu = \dot{\varepsilon}_\eta\end{gathered} \tag{4}$$

where:
Δt – time step,
$\bar{F}$ – magnitude of control signals,

Set of fuzzy values consists of:

$$\bar{F} = \{0[\boldsymbol{Z}];\ \pm small[N\ or\ P\ \boldsymbol{S}];\ \pm medium[N\ or\ P\ \boldsymbol{M}];\ \pm big[N\ or\ P\ \boldsymbol{B}]\}$$

ε_η – errors of position of the ship; $\varepsilon_\eta = [d_x, d_y, d_\psi]$
ν –speed variation error; $\nu = [u, v, r]$
τ_z – external disturbance forces
$f_{\Delta t}$ – function defined by the fuzzy controller
$f_{\bar{F}}$ – function defined by the fuzzy controller

In above equations, the values “0”- Z, “small”- S, “medium”- M and “big”- B are the amplitudes of the control signals. The controllers used in the control system are fuzzy logic controllers of Mamdani type [2, 8].

The control system contains fuzzy logic controllers. They are: course keeping controller, *x*-position keeping controller and *y*-position keeping controller [2, 8]. Those controllers are working independently to keep the USV hull center *CG* at the reference point R with the set course ψ_s. The ship rotation around z-axis is executed using the bow thruster and the main propellers, which generate opposite thrust. During the ship motion along the yb axis both the bow thruster and main propellers work in the same direction. While the ship motion along the x_b axis a force of thrust is generated only by the two main propellers [3, 6].

The main task of a ship is motion along a desired trajectory. This trajectory consists of a set of turning points are achieved by a ship. The road to the next turning point is continuously generated by changing coordinates of the reference point *R* by the fuzzy control system. Since the power of the propulsion system is limited, hull movements are delayed with respect to the moving of reference point. This delay is higher when the speed of reference point motion along the set trajectory is low or very low. Therefore the control algorithm includes a series of conditions relating to reference point movement [5, 8].

In adopted, in this article, the precision control algorithm it is assumed that the accepted range of the course error is $\Delta\psi_{max}$ and the accepted range of the position deviation is l_{max} (Fig. 6). The reference point *R* has just moved forwards, by the control system, when all above deviations are within accepted ranges. If the course error and/or the position deviation are larger than the accepted range, the reference point is stopped to wait until the controllers will stabilize the ship in the accepted range. In the Fig. 6 we can shows the process of controlling and achieving of the reference point *R* [8]. $WP_k(x_k, y_k)$ and $WP_{k+1}(x_{k+1}, y_{k+1})$ are coordinates of two waypoints of a segment of the desired trajectory [8]. The variable v_R is the vector speed along a segment of the trajectory for the reference point *R*. The angle *α* is used to determine the relative ship position with respect to the reference point *R*. When $l \leq l_{max}$ the ship motion is stable and the deviation is it means that the ship has the speed and a position identical with that of the reference point *R*. When $l > l_{max}$ the controller tries to curb the forward motion of the ship to keep the deviation position smaller than l_{max}. These situations are shown in Fig. 6.

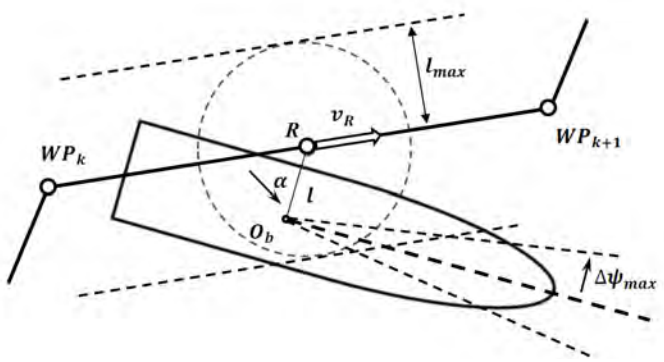


Figure 6 Reference point *R* along the trajectory by the USV. Coordinates in n-frame of turning points: $WP_k(x_k, y_k)$ and $WP_{k+1}(x_{k+1}, y_{k+1})$

4. SIMULATION STUDY

Simulation experiments have been made to confirm validity of the fuzzy precise control algorithm for the following assumptions [3, 8]:

- the mathematical model of the ship (3) is used to simulate the real USV's behaviour,
- the fuzzy control law is used with membership functions presented in Fig. 5 to precise control of USV,
- the controlled USV has to follow the desired path starting from the point WP_k and ending at the point WP_{k+1} with very low velocity *u*,
- vector of position and orientation of the ship is measurable.

To validate the performance of the developed fuzzy control law, simulations results using the Matlab/Simulink environment are presented below. The precise controlled ship has to follow the desired trajectory WP(xi, yi) beginning from WP_0 (250 m,0 m), passing turning waypoints: WP_1 (500 m, 1500 m), WP_2 (1500 m, 1250 m), WP_3 (1250 m, 0 m), and coming back to point of start WP_4 (250 m, 250 m). In simulation studies was assumed that the turning point was reached if the point *GC* of the controlled ship (in Fig. 6) is inside of the 10 m (a beam of the ship) circle of acceptance l_{max}. Tracking control simulation results for added disturbances and for a wind disturbances are shown in Fig. 7. Parameters of sea disturbances were wind speed 5 m/s and direction 135 deg in the Beaufort wind force scale *gentle/moderate breeze*. The case study has showed that a proposed the fuzzy control system enhanced good pitch and yaw control along of the desired path. The main advantage of the approach is its simplicity and satisfactory performance. The quality of precise control can be improved by adequate choosing of parameters of membership functions of input and output variables. Tuning of their values can be done by real sea trials.

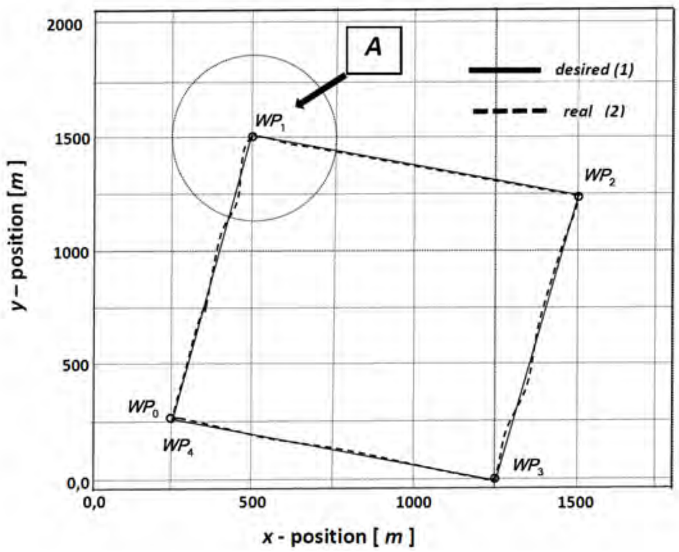


Figure 7 Movement of the ship in desired trajectory with influence of sea disturbances: desired trajectory (1), real trajectory (2).

5. CONCLUSIONS

The fuzzy control algorithm to application of the synthesis of precise control allows determination of the USV a trajectory in situations of manoeuvres in low speed. Algorithms of a fuzzy logic take also into the predicted time of the manoeuvre approximating the ship's dynamic properties and evaluates the final deviation of the real trajectory from the reference value. The simulation of horizontal plane motion of the ship precise controlled by the control system designed with fuzzy set theory has been considered. The nonlinear mathematical model of the ship in the low speed environment is applied in numerical experiments. Inserted simulation results illustrate the usefulness of the proposed approach to practical usage.

Future works will concentrate on identifying the best fuzzy structure of the control system of the USVand making tests of the described algorithms in real sea environment conditions. By decision-making in a fuzzy environment is meant a decision process in which the goals and/or the constraints, but not necessarily the system under control, are fuzzy in a real.

REFERENCES

[1] Driankov D., Hellendoorn H., Reinfrank M., An Introduction to Fuzzy Control. Springer-Verlag. Berlin, 1993

[2] Garus J., Malecki J., A Method of Precise Control of the Ship Based on Power and Torque of Propeller. In: Proc. of IEEE 27th Convention of Electrical and Electronics Engineers in Israel – Industrial Electronics & Industrial Applications, pp. 324-329, 2012.

[3] Garus J., Malecki J., Simulation of Plane Motion of Semiautonomous Underwater Vehicle. In: Proc. of 11th the European Computing Conference (ECC'11), 1pp.26-131, 2011.

[4] Lisowski J., The sensitivity of state differential game vessel traffic model. Polish Maritime Research, 2016, Volume 23, Issue 2, p. 14-18

[5] Malecki *J.*, Fuzzy Track-keeping Steering Design for a Precise Control of the Ship. Solid State Phenomena Vol. 196, pp. 140-147, 2013.

[6] Malecki J., Mathematical Model for Control of Ship at Slow Speed. Polish Journal of Environmental Studies, vol.16, No 4B, pp.126-130, 2007.

[7] Malecki J., Modelling of the precise movement of a ship at slow speed to minimize the trajectory deviation risk, in: Computational Methods and Experimental Measurements XIV, Southampton-Boston, pp. 295-303, 2009.

[8] Malecki J., Zak B., Design a Fuzzy Trajectory Control for Ship at Low Speed". In: Advances in Systems Theory, Signal Processing and Computational Science, WSEAS Press, pp. 119-123, 2012.

[9] Malecki J.: Applying of Fuzzy Logic to Precise Control of the Ship Motion. Second International Conference on Mathematics and Computers in Sciences and in Industry MCSI, 2015, p. 125-130

[10] Morawski L., Nguyen Cong Vinh, "Control of ship motion in manoeuvring situation. In: Proc. 2nd International Conference on Marine Research and Transportation ICMRT. Pp. 67-73, 2007.

[11] Sordelen O. J., Optimal Thrust Allocation for Marine Vessels". Control Engineering Practice. Vol. 5, No. 9, pp. 1223-1231, 1997.

OVERVIEW OF COMMUNICATION SOLUTIONS FOR INTERNET OF THINGS IN MARITIME INDUSTRY

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Summary

Recent expansion of Internet of Things (IoT) application areas has brought to significant number of tested applications and application proposals in maritime industry, which will significantly improve safety, efficiency and reliability of maritime transport. Such a development of different IoT applications in maritime industry is enabled by novel communication technologies, designed for fulfilling requirements of IoT applications. Besides well-known short-range communication technologies used in most of nowadays IoT services (IEEE 802.15.4 and IEEE 802.11 based solutions), recent development in satellite communication systems and mobile cellular systems have enabled these technologies to serve great number of IoT enabled devices through direct communication. In this paper we provide an overview of communication technologies for covering open sea areas (satellite communications and integrated 5G satellite-terrestrial) and close to coast areas (LoRa as representative of Low Power Wide Area Networks) with IoT services. We present systems' architectures, solutions on physical and higher layers, enabling protocols and technologies, as well as literature overview with performance results of these IoT enabling communication technologies, obtained through different conducted experiments.

Keywords: IoT, maritime industry, 5G, satellite communications, LPWAN

1. INTRODUCTION

Internet of Things (IoT) is novel paradigm of the connected smart physical and virtual entities, each with the unique identifier and with the abilities of sensing and/or actuating, data processing and sending/receiving over the communication infrastructure. IoT is the natural extension of the sensor networks and Machine to Machine (M2M) communication systems, which is expected to transform our society and industry in that manner, that it is denoted as Industry 4.0. According to the report issued by IoT Analytics, there were more than 7 billion of IoT connected devices in 2018, while the total number of connected devices (including smartphones, tablets, laptops or fixed line phones) was more than 17 billion, [1]. IoT Analytics predicts that till 2025, there will be about 22 billion of connected IoT devices, [1]. Areas of applications are numerous, and every day some novel solutions arise. Some of the most prominent application areas are smart grids, smart agriculture, smart buildings, environmental monitoring, e-health, industry process monitoring and smart transportation, including maritime transport. IoT in maritime industry is based on different kind of sensors installed onboard ships, in ports, container terminals, sensing platforms, unmanned vessels, smart buoys, etc., which are collecting and sending data using different communication technologies, to control stations and servers, where data is processed and stored. IoT applications will increase safety at sea, improve ship monitoring and goods tracking, enable efficient safety operations, control of autonomous vessels and unmanned vehicles, implementation of different new services on ships, etc., [2]. Among the other building components of IoT in Maritime Industry, communications solution arises as the particularly important and challenging, due to necessity to achieve efficient and reliable communications for great number of devices, regardless of whether the ship is in port, anchored or sails on the open seas.

The common communication architecture in IoT for maritime industry assumes usage of short range wireless communications technologies on ships or in marines, like are IEEE 802.15.4 (Zigbee or xBee) or IEEE 802.11 based solutions, where sensors send data to a sink node, which then forwards data using satellite, mobile cellular (2G/3G/4G) or WiMAX communication solutions, [3]. Usage scenarios and performance of the mentioned short range wireless communication technologies in IoT for maritime industry do not differ from other IoT application areas. Thus, in this paper we did not tackle these communication technologies. We provide an overview of communications solutions for covering coastal and open sea areas, i.e. satellite communications, 5G satellite-terrestrial communication systems and Low Power Wide Area Networks (LPWANs), which can also provide direct communication with IoT end-devices.

The paper is organized as follows. Overview of satellite communication system used for IoT in maritime industry is given in Section 2. For great number of applications in maritime industry sensors and actuators are located in remote areas where do not have support from terrestrial networks and only satellite systems can support IoT/M2M communications, [4]. Novel satellite communications systems support IPv6 (Internet Protocol version 6) and can serve great number of IoT devices through direct communication links, thus opening space to many new IoT applications.

Fifth generation mobile networks (5G), as a new generation of wireless access technology supports principle that everything will be connected inside one network all the time and anywhere. It will incorporate new satellite technologies in order to expand coverage all over the world. Thanks to this integration a lot of new services and applications based on high speed data rates will be implemented in maritime industry, including control and monitoring of fully autonomous ships in the future, [5], [6]. 5G satellite systems are described in Section 3.

Section 4 presents implementation of LoRa communication system, as representative of LPWAN, for coastal areas coverage. LoRa provide reliable communications which can be implemented for maritime applications that do not request high data rates, [5]. Couple of experiments were already realized and the obtained results are compared in this paper. It has been shown that LoRa communication system will be suitable for use for ranges up to 30 km from the shore side.

Section 5 gives concluding remarks.

2. APPLICATION OF SATELLITE COMMUNICATIONS FOR INTERNET OF THINGS

Satellite communication systems play important role in IoT in maritime applications, [8]. This is expected, as in sea areas far away from the coastline, which cannot be served by terrestrial access networks, satellite communications are almost irreplaceable communication solution. A lot of IoT and M2M applications require end-nodes to be grouped according to the task or information that have to send/receive. These applications can be supported via satellites by exploiting broadcast (i.e., towards all nodes in the network), multicast (i.e., towards a part of nodes from one network) or geocast (i.e., towards part of nodes inside certain area of the network) service. Satellite communications enable broadband services for passengers and crew on vessels, monitoring and control of crew and autonomous ships operations, IoT applications which require data transfer to or from the oceans, such as fishing buoys, fisheries, container tracking, bilge and exhaust discharge monitoring that help make the oceans safer and cleaner, etc., [9].

Satellites can provide high availability of communication links at all sea areas, for reasonable price, with true alternative path always available. Almost 100% availability is achieved by using Adaptive Coding and Modulation (ACM) techniques as specified in Digital Video Broadcasting - Satellite Second Generation (DVB-S2) standard, [10]. Round Trip Time (RTT) of 600-700 ms through Geostationary Earth Orbit (GEO) satellite link is just couple of hundreds milliseconds higher than RTT of a long terrestrial link and is suitable for most of the IoT and M2M applications. For the fully controlled automated systems, which are sensitive to high signal delay (RTT required to be very short) Low Earth Orbit (LEO) satellite constellation should be used. On the other side several adjustments and/or improvements in satellite systems for IoT should be made, such as development of specialized MAC (Medium Access Control) protocols for the access of end-nodes (sensors, actuators) to satellite resources, use of IPv6 through satellite link, interoperability between satellite and terrestrial networks and resource allocation and transmission management for group-based communications, [4].

Satellite networks can easily support concepts like Wide Area Situational Awareness (WASA), made to collect data from different sensors or end-nodes, process the data and based on that act effectively or predict future problems. WASA will be based on Wide Area Measurement Systems, which are also collecting data from sophisticated sensors and process them in real time, [11]. These systems can be implemented for monitoring conditions on oceans surfaces (buoys, moored platforms, etc.), to monitor traffic, environmental pollution hazards in some areas or for emergency management.

2.1. Principle of satellite communications in IoT applications

An example of the satellite communication with sensors as end-nodes is shown on Fig 1, [4]. As it can be seen, satellite is collecting data from numerous sensor nodes and sends it to ground station for processing. Control data are sent in reverse direction. There are two types of interconnections between the satellite and sensor nodes, direct and indirect access. In direct access mode sensors and actuators are communicating directly with satellite. Uplink communication is established with sensors and downlink communications with actuators. In indirect access mode, sensors and actuators are connected in Wireless Sensor and Actuator Network (WSAN) which is than connected with satellite through bidirectional sink node, [12]. WSAN enables multiple satellite links to be replaced with only one link, which significantly reduces system costs and complexity. Inside WSAN, sensors and actuators are connected through radio communication interface.

Interest for using low cost small satellites (< 50 Kg) in LEO is increasing nowadays, e.g. nanosatellites or CubeSats, [4]. Nanosatellite constellations have two important advantages. One is possibility to launch them as secondary payloads, which greatly reduces the launch cost, and the other one is that they can be built by integrating low cost components even if they are specially designed for satellite/space applications. This type of satellites is suitable for delay tolerant applications (e.g., environmental monitoring) because of low data rate communication. Different satellite operators already provide integrated systems for IoT and M2M solution packages based on satellite communications [29], [31], [32].

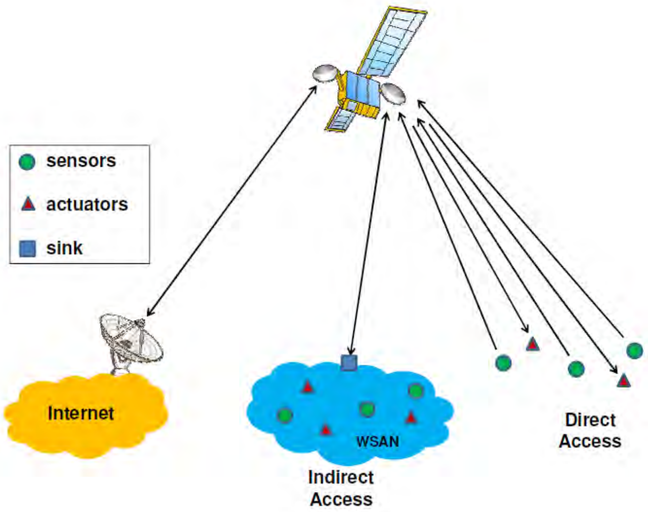

Figure 1 Satellite communications in IoT and M2M applications

Source: De Sanctis, M., Cianca, E., Araniti, G., Bisio, I., Prasad, R.: Satellite Communications Supporting Internet of Remote Things, IEEE Internet of Things Journal, 2327-4662 (c) 2015 IEEE

2.2. Protocols for satellite IoT communications

In M2M communications over satellite systems, most of the used protocols are proprietary solutions, which usually do not support Internet protocols, but with the expansion of IoT, the tendency is in design of IP enabled solutions, [4]. The challenge is in selection of the appropriate model for evolving from IPv4 to IPv6 of satellite system. One of the solutions in satellite IoT systems is implementation of DVB-S2 standard for forward link (link from gateway to end-nodes) and Digital Video Broadcasting – Return Channel via Satellite (DVB-RCS2) standard for the return link (from end-nodes to gateway, which supports IPv6 and uses Generic Stream Encapsulation (GSE), [4].

There are three main classes of protocols used for satellite IoT communications: (a) protocols targeting the Service Oriented Architecture (SOA); (b) protocols implementing the Representational State Transfer (REST) and (c) message oriented protocols, [13]. The most important representatives of REST and message orientated protocols are Message Queuing Telemetry Transport (MQTT) and Constrained Application Protocol (CoAP), respectively.

Publish/Subscribe (PUB/SUB) is paradigm typically used for IoT scenarios and allows the data consumers, or subscribers, to receive any fresh data as soon as they are available at the data producers (end-nodes). The main role of (PUB/SUB) paradigm is to separate data producers and data consumers inside intermediate entity, called broker. In PUB/SUB systems which are topic based, each data frame belongs to one or more topics, or logical channels. Every time when publishers send new data, broker have to specify topic(s) under which new data belongs. Broker keeps a list of active topics and for each topic a list of active subscribers. Each subscriber declares its interests to the broker through registration procedure. Once the system is set up, broker is collecting data and sends it to subscribed nodes.

2.2.1. MQTT Protocol

MQTT protocol for IoT applications in satellite communications was designed by IBM in 1999, and has widespread use for terrestrial communications. Data packet consists of 2 bytes header section, variable header part, which depends on the packet type and variable length payload, [13]. Each data packet is sent to broker, which maintains list of topics and registered subscribers. MQTT is based on Transmission Control Protocol (TCP) which guarantees reliable data exchange over the network connection between broker-publisher and broker-subscriber. MQTT offers three Quality of Service (QoS) levels. System based on MQTT protocol is shown on Fig. 2, [13].

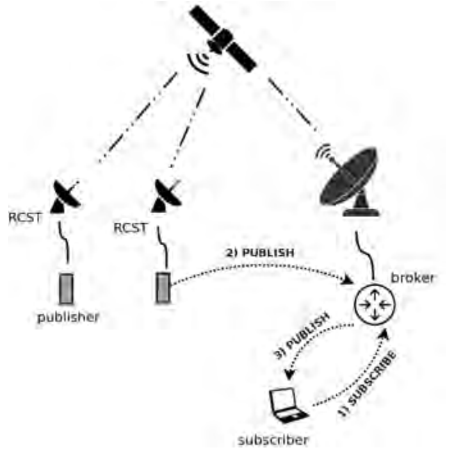

Figure 2 The MQTT-based scenario system. The dotted lines show a typical setup procedure at application layer (step 1) and the notification of new messages via broker (steps 2 and 3).

Source: Baco, M., Colluci, M., Gotta, A.: Application Protocols enabling Internet of Remote Things via Random Access Satellite Channels, IEEE ICC 2017, Paris, France, 21-25 May 2017.

2.2.2. CoAP Protocol

CoAP is REST architecture and UDP based protocol, used for resource constrained environments. Each server logically encapsulates a resource, which is identified by Uniform Resource Identifier (URI). In order to retrieve the resource representation available on the server, CoAP client sends requests for confirmable or non-confirmable messages. If confirmable message is transferred, acknowledgement (ACK) will approve that message is correctly received. On the other side, transfer of non-confirmable message is not reliable. CoAP message consists of fixed size header (4 bytes), variable Token field (0-8 bytes), options field and payload, [13]. For reliable data transfer can be used optional field at the application layer. Sample of CoAP communication scenario is presented on Fig. 3. System consists of numerous CoAP servers, connected to CoAP proxies and each proxy is connected to RCST (*Return Channel Satellite Terminal*). CoAP servers present end-nodes with sensors and produce data which is transferred via DVB-RCS2 compliant RCST to remote CoAP client (or more of them) for further processing.

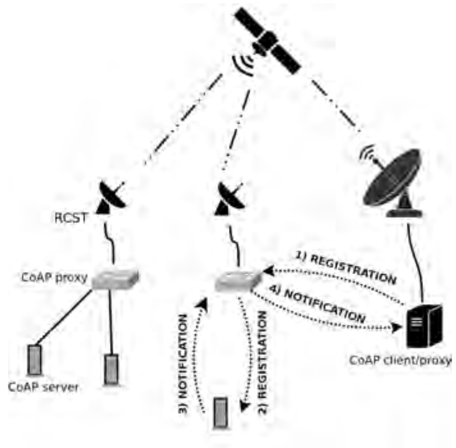

Figure 3 The CoAP-based scenario system. The dotted lines show a typical setup procedure at application layer (steps 1 and 2) and the notification of new messages via proxy (steps 3 and 4).

Source: Source: Baco, M., Colluci, M., Gotta, A.: Application Protocols enabling Internet of Remote Things via Random Access Satellite Channels, IEEE ICC 2017, Paris, France, 21-25 May 2017.

In [13] CoAP and MQTT protocols were experimentally tested and compared. Key difference between them is in transport protocol. MQTT (TCP based) is connection orientated and requests Three Way Handshake (3WHS) procedure to establish a connection. On the other side CoAP (UDP based) realizes connectionless communication and does not provide any flow control algorithms. At least 1000 of data exchanges were simulated for each scenario with low/moderate load and results were compared. In IoT/M2M scenarios CoAP protocol provides couple of advantages over MQTT because of the length of the transmission window, which can be adjusted at the application level. CoAP provides higher flexibility and exhibits a lower overhead, making it very suitable for these purposes. According to obtained results, CoAP outperforms MQTT in attained performances on Random Access (RA) satellite channels and because of that, future research will be based on CoAP, [13].

2.2.3. MAC Protocols

Proper choice of multiple access scheme is very important in order to achieve efficient use of satellite resources. Time Division Multiple Access (TDMA) is suitable multiple access scheme, but not for great number of end-nodes, which are sending data only periodically. DVB-RCS2 supports contention free and contention based multiple access, [4]. Multi-Frequency Time Division Multiple Access (MF-TDMA) satellite channels are used for communication to gateway. These channels are coordinated by Demand Assigned Multiple Access (DAMA) in order to properly share available satellite capacity between active end-nodes. Network Control Centre (NCC) controls when each end-node can transmit. In case that allocation is made for end-node which does not have date to send, capacity of satellite link is wasted, [4].

In the DVB-RCS2 standard Slotted ALOHA and Contention Resolution Diversity Slotted ALOHA (CRDSA) methods are used. CRDSA is grouping timeslots into frames and terminal generates sets of packet replicas which are sent using a pseudo random timeslot inside a frame. With this method, low terminal price and high transmission efficiencies are accomplished, [14].

New algorithm for satellite data collection from end-nodes in direct access mode is proposed in [15]. Algorithm consists of searching and allocating phase. During searching phase satellite will find end-nodes which have data to send and will divide them into two groups. After repeating this process for certain number of times, nodes without available data to send are removed from the group. For the remaining nodes in allocation process, satellite timeslots will be assigned. With this algorithm, higher bandwidth efficiency can be achieved in comparison with TDMA based or ALOHA scheme, [15]. In indirect access mode MAC protocol is proposed, because it saves the overall energy consumption during synchronization phase, as protocol uses relatively short pulses for wake-up signal, [16].

2.2.4. IPv6 over Satellite

The use of IPv6 is very important element of IoT. IPv6's huge increase in address space is an important factor in the development of the IoT in order to be able to assign an IP address to billions of future simultaneously connected end-nodes. DVB-RCS2 supports IPv6 and Generic Stream Encapsulation (GSE) is used in order to reduce the levels of encapsulation and improve efficiency, [17]. According to DVB-RCS2 standard, IPv6 packets received on the LAN interface of a RCST are forwarded according to the RCST IPv6 routing table or can be redirected to an internal agent (e.g. Performance Enhancing Proxy - PEP, intercepting proxy, etc.) for processing prior to transmission. Before packets for transmission are sent over the air, interface should be forwarded to the QoS module for transmission over the satellite, [4].

3. IMPLEMENTATION OF INTEGRATED 5G SATELLITE-TERRESTRIAL SYSTEMS FOR IoT IN MARITIME INDUSTRY

5G networks are going to be networks which incorporate different technologies like satellite, Wi-Fi, small cells and traditional mobile networks in one global communication ecosystem, [6]. Satellites will enable service provisioning to end-users wherever they are located and without available terrestrial infrastructure. There are couple of very important characteristics which will contribute to success of 5G networks provided by satellites, like wide coverage area, affordable price and reliability. Satellites will support IoT services for vessels which are sailing in areas out of coverage of any other communication network and will provide service continuity and connectivity for different types of ships, including newly developed autonomous ships. Some of the most important features of 5G for implementation in IoT applications are: (a) complementing connectivity for mobile end-nodes (ships, aircrafts, platforms); (b) offloading temporarily congested networks; (c) providing backhauling services to fixed or moving base stations and (d) to provide communications in case of emergency, [6]. Instead of broadcasting, future satellite communications will play an important role in providing broadband connectivity for vessels and aircrafts, especially with development of small satellite systems and mega constellations, [5]. Satellites are able to deliver very high data rates in broadcast, multicast and unicast mode. New constellations of LEO (*Low Earth Orbit*) satellites can deliver high capacity services to localized areas, and more of them will be installed until 2020 to support 5G networks.

5G services are divided into three generic groups: Enhanced mobile broadband (eMBB), Massive machine type communications (mMTC) and Ultra reliable and low latency communications (URLLC) according to ITU Radiocommunication sector, [18]. eMMB service will support very high data rates (up to 20 Gbit/s peak data rate on DL), mMTC will be implemented for serving great number of end-nodes (up to 10^6 nodes per km^2) with low data rates, where end-user nodes are expected to have long battery life (up to decade) and URLLC will achieve only 1 ms user plane latency, and thus will be used for smart grids, vehicle to everything communications (V2X) and for transportation safety. New solutions that enable 5G networks to meet IMT-2020 requirements are massive multiple-input multiple-output (mMIMO), milimeter wave communications and networks densification, [21]. Some advances are necessary in network layer in order to support efficient operation in different radio technologies and applications. In 5G networks, principle of network programmability can be applied to enable development of new optimisation mechanisms, such as network slicing. Network slicing principle achieves efficient resource allocation when virtual mobile network operators share same physical network operated by virtualized infrastructure provider.

One of the most important things for successful implementation of 5G networks, and for achieving such a plethora of services with different service demands, is dedication of appropriate spectrum. There are three 5G pioneer bands ready for use in Europe and approved by European Commission. 700 MHz band (694-790 MHz) is assigned for wide area coverage including indoor coverage and supports mMTC and URLLC services, 3.4-3.8 GHz band is suitable for urban areas and supports eMBB service, and 24.25-27.5 GHz band will be used for hot spots and eMBB services (in USA and Korea will be 28 GHz), [19]. Spectrum sharing technique is very important for integrated 5G satellite networks and depends on satellite system characteristics such as link length, transmission latencies or size of coverage areas. Spectrum sharing job is being done in terrestrial domain and some of techniques include power control, beam hopping and spectrum databases. Spectrum database technique does not allow to any secondary user inside network to access spectrum before it receives information from database that specific channel is free at the user location, [5]. Recently developed representative of spectrum database approach is licensed shared access (LSA), [22].

Integration of satellite networks and 5G networks for specific applications and services is enabled by using cloud computing and cloud networking like main drivers. Multi-access edge computing (MEC), software defined networking (SDN) and network function virtualization (NFV) are the most popular enablers for dynamically programmed networks through centralized network points, [20]. User terminals flexibility is supported by software defined radios (SDR). All these mechanisms will support development of satellite networks that can be updated on the fly, as opposed to existing fixed systems.

3.1. Architecture of 5G satellite-terrestrial integrated systems

Integration of satellite access network and terrestrial mobile networks is not simple task, because of the static management of traditional satellite services. An example of 5G satellite-terrestrial system is shown in Fig. 4, [5]. Satellite network architecture consists of satellites connected with gateways and satellite terminals with asymmetric links. Satellite systems do not provide computing resources which would allow them to host radio access networks (RAN) or core network functions of the terrestrial networks, [5]. In the presented system different radio access technologies (RAT), like 5G network, LTE and Wi-Fi are incorporated. User equipment (UE) here assume any kind of multi-radio terminal, including satellite terminal. QoS management for transferred data is enabled by 5G core, which also monitors cooperation between satellite and terrestrial segments. RANs are responsible to provide multitenancy support, which enable different operators to share network resources between each other and with virtual operators and end-to-end network connectivity through them. Software defined networking (SDN) controller has control over network devices and global knowledge about the network. At the edge of the network, localized computing and storage resources for different applications are provided with multi-access edge computing (MEC). MEC capabilities can be dynamic and scalable, as MAC is based on cloud concept. As long service delivery delay is not affected by the backhaul, satellite can provide reliable link for edge computing, which is essential for low latency services. SDN and network function virtualization (NFV) technologies are playing main role in the integration of satellite and terrestrial networks, [5]. Integrated 5G satellite-terrestrial networks can provide different kind of services with global coverage and reliable access, also with use of data processing and content caching at the mobile edge.

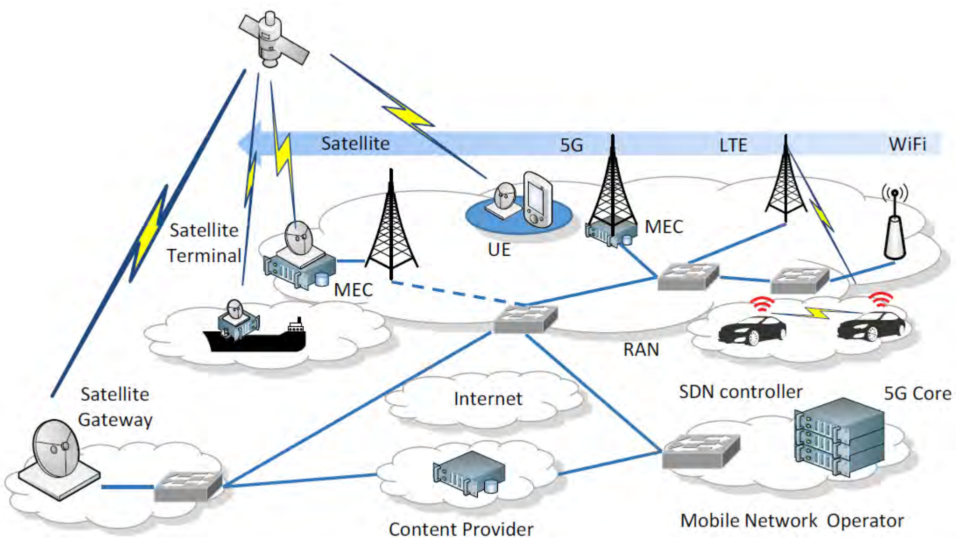

Figure 4 Integrated satellite-terrestrial system

Source: Höyhtyä, M., Ojanperä, T., Mäkelä, J., Ruponen, S., Järvensivu, P.: Integrated 5G satellite-terrestrial systems: Use cases for road safety and autonomous ships, 23rd Ka and Broadband Communications Conference (KaConf), Trieste, Italy, October 2017.

3.2. Autonomous ship connection with 5G satellite-terrestrial integrated networks

Many companies, which are dealing with ships automation systems, are planning to develop fully autonomous ships. These will include IoT technologies, artificial intelligence and marine autonomous systems. Rolls-Royce predicts presence of remote unmanned coastal vessels by 2025, and by 2035 to have fully autonomous crewless cargo ships, [23]. Norwegian companies Yara International and Kongsberg are already building fully autonomous electric vessel which will start with remote operations in 2020, [24]. Important role in these cases will have 5G satellite networks, which will together with existing terrestrial networks provide reliable, high data rate communications with vessels wherever they sail on the Earth. Number of cargo and passenger vessels is growing up every day and we will have problem with supply of seafarers in the future. On new autonomous vessels, electrical equipment will control most of automated routine tasks but navigational and technical jobs will be transferred to remote operation center (ROC).

In [5] is presented communication architecture of an autonomous ship and one system example is shown in Fig. 5. One of the most important components of this system is connectivity, [25]. Communication must be supported by multiple systems because of redundancy. Bidirectional, reliable and accurate communications should be provided, with sufficient communication link capacity for remote control and sensor monitoring.

Communication architecture for autonomous ship can be divided in two parts, [5]. First part refers to in-ship communications and controls all data related to navigation procedures, sensors reading, machinery status, situational awareness and safety systems. According to collected data, ships' automation system will be able to make independent decisions, proceed with proper commands and sail safe in different environments. Second part is communication with other ships and with shore side control centers. There are operators in ROC who are monitoring one or more ships like „virtual captains". Even each autonomous ship must be able to make decisions for different situations, according to data collected from navigational equipment and sensors, during critical or difficult operations control will be taken by „virtual operators", [26]. Communication architecture used in this case is 5G satellite-terrestrial hybrid network. In case that communication cannot be established via satellites, ship can establish multi-hop mobile ad hoc network with other ships, and through them to terrestrial 5G network and ROC, [5]. In this way, higher redundancy and reliability is attained. Ships can use integrated network to send data about their navigational information, location and status of the other ships in the same area, to the shore control center.

In order to have full control, autonomous ship should be able to send sensors' data to ROC with speed of couple of Mbits per second. This speed is requested to manage data transfer, consisting from light detection and ranging (LiDAR) sensors and video cameras to shore control and monitoring center. This means that high capacity uplink and low capacity downlink are necessary. In regular networks, which are now in use, the opposite situation is presence. Depending on communication technology, position of antennas and transmitted power, it will be possible to use terrestrial networks up to 100 km from the shore and satellite networks for higher ranges, [27].

The last, very important component of 5G satellite-terrestrial network is connectivity manager responsible to guarantee quality of service (QoS) for communications. It will be responsible for choice of proper radio access technique (RAT) and data route in order to provide end-to-end resource management. In most of situations, communication will be established simultaneously through different access technologies like different satellite systems, terrestrial networks (4G, 5G), WiFi, VHF, etc. Main roles of connectivity manager are to set up and designate data to adequate communication channels and routes, to prove that data is delivered to destination with proper latency and to communicate with ships in close vicinity to verify that everyone will obtain required service, [5], [28].

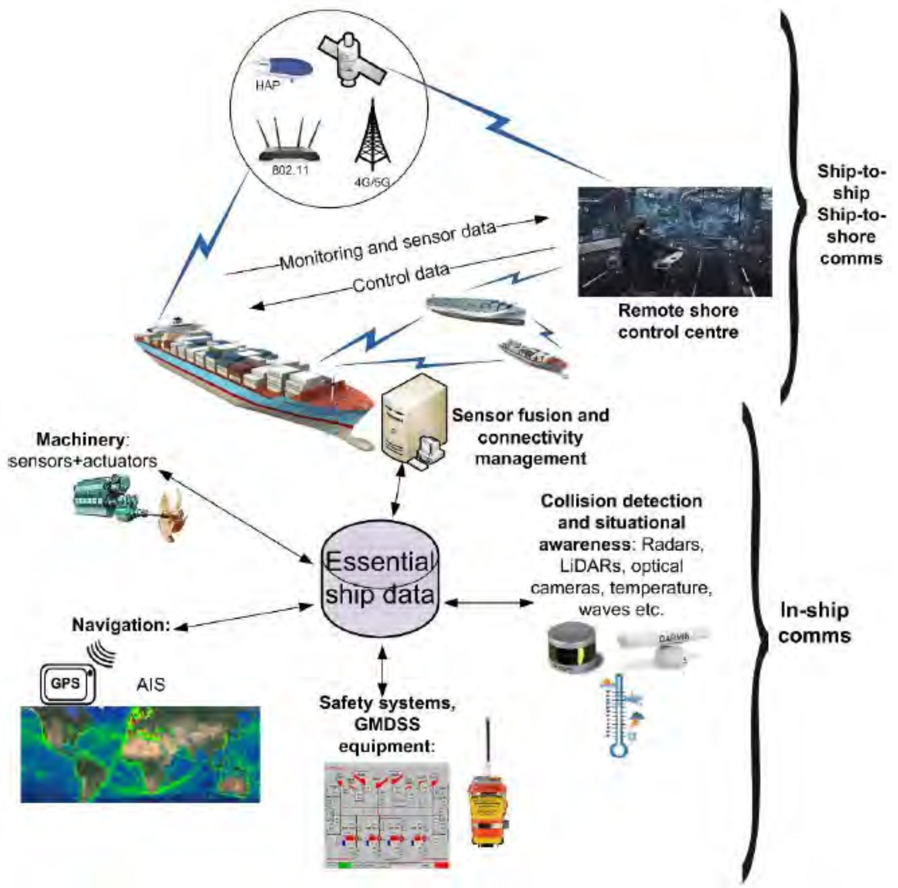

Figure 5 Communication architecture of an autonomous ship

Source: Höyhtyä, M., Ojanperä, T., Mäkelä, J., Ruponen, S., Järvensivu, P.: Integrated 5G satellite-terrestrial systems: Use cases for road safety and autonomous ships, 23rd Ka and Broadband Communications Conference (KaConf), Trieste, Italy, October 2017.

3.3. 5G Satellite-terrestrial systems in use

There are couple of independent 5G satellite systems which are in process of developing, and some of them are already in use, [29], [31], [32]. They are mainly made to support IoT/M2M services. 5G satellite networks are alternative for existing L-Band, VSAT (Very Small Aperture Terminal) and 3G/4G networks for M2M and other maritime applications.

Wireless Maritime Services (WMS) is company which provides cellular mobile, Wi-Fi and IoT services to the maritime market. They started with implementation of 2G, 3G and 4G networks on cruise ships long time ago and they are now improving their communication solutions through deploying 5G networks, [31]. They are working on coupling 5G technology with low and medium earth orbit satellites in order to create a system which will enable cruise lines to enhance guest and crew experiences, improve marine safety operations and support industrys' environmental sustainability efforts.

IoT/M2M telemetry devices and sensors, data connectivity, network management and software applications represent smart asset technology stack, which can be used for complex container supply chain operations. Application of GSM networks on the ships creates a floating Wi-Fi network that allows onboard monitoring of all M2M equipped containers. This is very valuable for temperature sensitive shipments inside reefer containers and has the highest growth potential. Mearsk Line, as a largest single user of this system, has installed M2M telematics incorporating ORBCOMM technology on its 270,000 reefer containers, [29]. This trend will continue with 5G networks and advances in new satellite technologies. ORBCOMM is the only satellite operator in the world dedicated only to M2M services which recently launched its second generation network OG2. OG2 enables service to up to six times higher number of end-users and up to twice higher transmission rate than existing OG1 with LEO satellites, [29]. New system enables faster message delivery, larger message sizes and better coverage at higher latitudes with significant increase of network capacity.

Leosat introduced LEO satellite constellation which will be dedicated for data transmission and is constructed for enterprise connectivity, with capacity for connecting offshore drilling rings and shipping in remote ocean areas for IoT/M2M applications, [32]. New system will need constellation of up to 84 satellites and first 13 will be launched in 2020 for network testing.

Medium Earth Orbit (MEO) satellites will have important role in providing fast broadband services over the seas. SES Networks provides some of the fastest broadband connections to cruise ships with its O3B MEO satellites constellation. O3B system will provide possibility for use of Facetime, Skype, video over IP and live gaming to end-users. SES has plan to expand O3B with the mPower constellation of satellites starting Q1 2021 and to provide more bandwidth in some today uncovered geographic locations, [32].

4. LOW POWER – WIDE AREA NETWORKS (LPWANS)

There are different communication options adopted for different kinds of services in coastal areas, e.g., ship/boat monitoring, maintenance of navigation marks, date extraction from sensing platforms, unmanned vehicle management, safety applications, etc., [23], [33]. Low Power – Wide Area Networks (LPWANs) are very popular communication solution for these purposes, due to their well-known characteristics, which are great transmission range (more than 15 km) and end-nodes' low power consumption (battery lifetime of years). LPWANs are emerging networks, which design is very suitable to support huge variety of IoT marine applications, [7]. Comparison of the transmission range and energy efficiency for different communication technologies that support IoT are shown on Fig. 6, [2].

High date rate is not important design factor for LPWANs, but they meet main IoT systems requirements such as: (a) long communication range; (b) reduced use of bandwidth per message; (c) daily limited number of messages per each node; (d) high network capacity; (e) low hardware complexity and low cost of devices. Even LPWANs have much in common with Wireless Sensor Networks (WSNs) there are couple of main differences. The major one is that instead of WSNs mesh topology and multi-hop routing, LPWANs require setting up gateways to serve end devices. Also WSNs were developed for short ranges. Up to now were developed different kinds of LPWAN based technologies and one of the most prominent is LoRa (Long Range), [2], [7], [33]-[37].

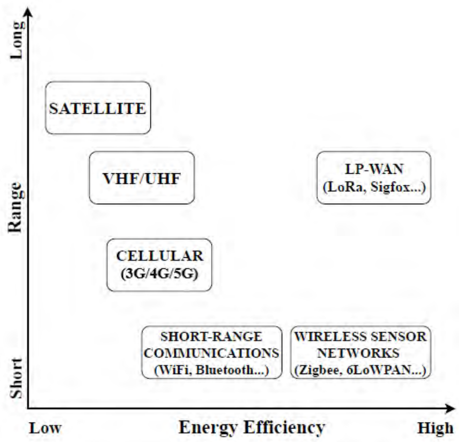

Figure 6 Comparison of transmission range and energy efficiency provided by different communication technologies employed in maritime IoT.

Source: Sanchez-Iborra, R., G. Liaño, I., Simoes, C., Couñago, E., F. Skarmeta, A.: Tracking and Monitoring System Based on LoRa Technology for Lightweight Boats, Electronics 2019, 8, 15;

4.1. LoRa

LoRa is new communication technology developed for long communication ranges with reduced power consumption and battery life of approximately 10 years, [36]. Main LoRa strategies are to use low bit-rates transmission, sub-GHz frequency bands (in accordance with local regulations) and limited end devices' processing capabilities.

As per LoRaWAN (LoRa Wide Area Network) specifications, there are three major components of this communication technology, namely, the PHY layer, the link layer and the network architecture.

When the PHY layer is concerned, LoRa modulation is based on Chirp Spread Spectrum (CSS) modulation technique, which enables use of low-quality oscillators in end devices and it enables fast and reliable synchronization process. CSS scheme is using wideband linear frequency-modulated pulses whose frequency increases or decreases over specific amount of time based on encoded information. Use of high bandwidth-time product makes radio signals resistant on in-band and out-of-band interferences and as result we have the maximum link budget of 157 dB, [7]. There are two low frequency bands in use, 868 MHz in Europe and 911 MHz in the USA. Both of them are assigned for Industrial, Scientific and Medical (ISM) purposes, meaning that are unlicensed and free for use. In order to avoid band overloading, LoRa is using only short data packages in communication and limited amount of massages from each end device per day. There are three important configuration parameters: (a) Spreading Factor (SF) which defines the grade of transmitted signal spreading comparing to the original one. This is the most important parameter and higher SF means longest spreading with the highest transmission robustness and lowest data-rate; (b) Coding Rate (CR) which determines amount of redundant information sent inside transmitted packet and is necessary for recovering corrupted data in receivers; (c) Bandwidth (BW). Different channel bandwidths are in use, but the most employed is 125 KHz.

At the link layer, MAC protocol defines three options for scheduling the receive window slots for downlink communication, named as classes A, B and C. All end devices support at least class A and requests that two receive windows are open after each uplink frame transmission as it is shown in Fig. 7, [7].

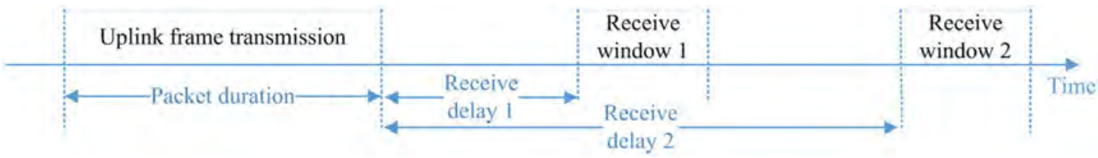

Figure 7 Communication phases of a class A LoRaWAN device.

Source: Petäjäjärvi, P., Mikhaylov, K., Pettissalo, M., Janhunen, J., Iinatti, J.: Performance of a low-power wide-area network based on LoRa technology: Doppler robustness, scalability, and coverage, International Journal of Distributed Sensor Networks, 2017, Vol. 13(3)

The LoRaWAN specification [37] defines network topology and security specifications for LoRa networks. LoRaWANs usually use star or star of stars' network topology, where gateways relay data massages between the end devices and network server as is shown in Fig. 8, [2]. In this way end-devices communicate directly with the base stations without any support from the other end devices in the same network.

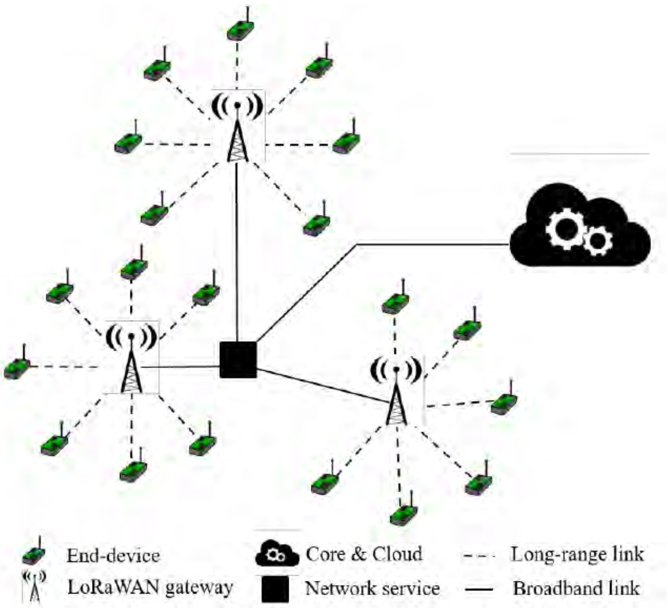

Figure 8 LoRaWAN network architecture

Source: Sanchez-Iborra, R., G. Liaño, I., Simoes, C., Couñago, E., F. Skarmeta, A.: Tracking and Monitoring System Based on LoRa Technology for Lightweight Boats, Electronics 2019, 8, 15; DOI:10.3390/electronics8010015.

4.1.1. Applications of LPWAN

LPWANs support different applications on land and at sea, such as smart metering applications (e.g. gas, water, electricity, and garbage), civil engineering and infrastructure monitoring (e.g. tunnels, bridges and buildings), environment conditions (pollution and climate), tracking of vehicles (e.g. cars, bicycles, and motorcycles), etc., [7].

LPWANs and LoRaWANs, as its representative technology, already enable implementation of low cost, power efficient and long range wireless communications for maritime environments. The recognized limitations of these wireless networks, such as short packet length, low data-rate and sensitivity to Doppler effect even for end devices' speed over 38 km/h (SF12) [7], do not put any restrictions for the most of coastal appliances.

LoRaWANs can be used for monitoring and alerting operations for ships coastal areas, [2]. Besides this, ships can send data about their state and position and system can have similar function like AIS (*Automatic Identification System*). Another potential field of application is for marine autonomous vehicles, e.g. Unmanned Surface Vehicles (USV), Unmanned Aerial Vehicles, or unmanned ships which are already in use or under testing procedures. Moored platforms and buoys for monitoring environmental conditions and oceanic metrics can be also connected in LoRaWANs. In this case data collection can be automatically scheduled and it does not depend on weather conditions.

Michelin, Sigfox France and Argon Consulting have launched new solution for tracking of sea-freight containers based on Sigfox's technology (LPWAN) and global satellite network, which design is based on low cost and low energy consumption principles, [30]. This system will allow shippers to follow their sea containers shipments in real time and will increase for 40% Estimated Time of Arrival (ETA) accuracy. It will also decrease by four times inventory ruptures caused by exception events, like bad weather conditions.

4.1.2 Experimental implementation of LoRa

LoRa system has been already experimentally tested in maritime applications and results were published in [2], [7]. Hereinafter we will mention two experimental works and obtained results.

In [2] LoRa communication system was implemented to monitor evolution of light and small boats races. LoRa monitoring devices were mounted on racing boats equipped with different types of sensors for position and other measurements in port of Vigo, Spain. Base station was installed on the top of Port building, with antenna mounted 3 m above the sea level. Tracking platform, available through the Internet, was developed, jointly with dashboard for live race monitoring. 14 dBm output transmission power is used in the 434 MHz band with 1/4 wave helical dipole antenna mounted on position not higher than 80 cm above the sea. In communication process were used messages of full length of 52 Bytes. Packet Delivery Ratio (PDR), time on air (ToA) and Received Signal Strength Indicator (RSSI) of each transmission were measured during experiment with SF7 and SF12, using bandwidth of 125 kHz. According to the obtained results, by using SF7 configuration, greater data transmission can be obtained. Both systems were showing high transmission links robustness, as there was no any lost packet except in the non-coverage area. RSSI reception levels (dBm) during the tracking are shown in Fig. 9, [2]. Test was also conducted in order to evaluate transmission range in open sea with SF12 and maximum coverage for this kind of boats was 4 km. With available battery of 900 mAh system had autonomy of 6.5 hours.

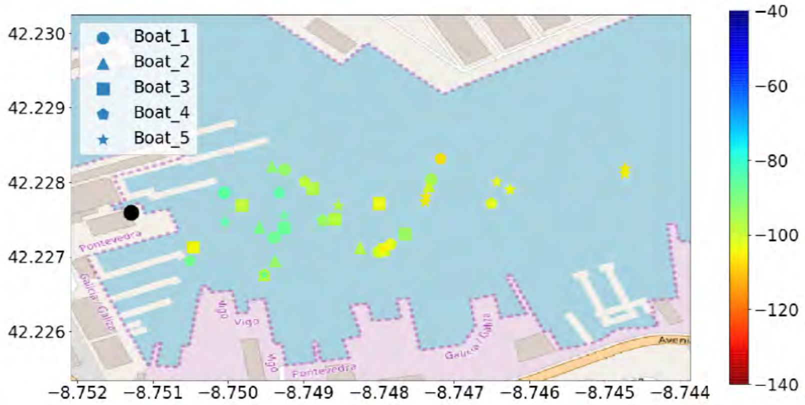

Figure 9 RSSI reception level (dBm) attained during the tracking of a training session

Source: Sanchez-Iborra, R., G. Liaño, I., Simoes, C., Couñago, E., F. Skarmeta, A.: Tracking and Monitoring System Based on LoRa Technology for Lightweight Boats, Electronics 2019, 8, 15; DOI:10.3390/electronics8010015.

The other experiment was done in Oulu, Finland, [7]. In this case gateway's antenna was installed on the top of University of Oulu building, 24 m above the sea level and 5.1 km far away from the port where testing boat was located. End-device was boat with integrated GPS and other sensors and transceiver with antenna installed on its mast, 2 m above sea level. Transmission power of 14 dBm and SF12 were used during the tests. Operating frequency was 869 MHz. System configuration assumed that end device sends reports every 5 s. Measurements were taken for higher ranges compared with the previously described experiment in port of Vigo. Results are presented in Table 1, [7].

Table 1 Results of the coverage measurements of the LoRa technology, [7]

Range [km]	No. of transmitted packets	No. of received packets	Packet success ratio (%)
5-15	2998	2076	69
15-30	690	430	62
Total	3688	2506	68

In the first described experiment it was proven that LoRaWAN technology can be used for the distances of 4 km with high reliability, what should be enough for maneuvering in most of the ports. From the second described experiment it can be seen how reliability of LoRA links drops down with distance increase between end-device and gateway. Within 5-15 km range 69% of packets were successfully delivered and 62% within range of 15-30 km.

5. CONCLUSION

Recent development of ICT, especially IoT paradigm, has enabled progress of maritime industry towards more efficient, reliable and safe industry branch. As a result of all this improvement today we have in use smarter ships, intelligent cargo tracking systems and highly automated processes in maritime industry. An important building block of IoT, which significantly contributes to IoT expansion in maritime industry is communication technology, especially different wireless communication solutions. Thus, in this paper we provide an overview of communication technologies which enable IoT services close to coastal areas, like are LPWAN and 5G communication systems, and in open sea areas, like are satellite communication systems and integrated 5G satellite-terrestrial communication systems.

Satellites play important role in maritime communications, and their importance will be even greater in the future. We present satellite network structure for support of IoT services and different protocols for achieving IoT services over satellite communications are described and compared. In the area of IoT for maritime industry, there is a growing interest in understanding of potential use of nanosatellites constellations.

Satellites are very important component of 5G communications landscape and they do not have competitors in providing different type of services in wide coverage areas. In order to provide seamless service coverage in all areas around the globe, combined 5G satellite-terrestrial systems are in developing process. We described system architecture of the integrated 5G satellite-terrestrial system, required technologies for integration and some possible applications. Implementation of integrated system for autonomous ships was described, as it is the only communication infrastructure which support this upcoming concept. The existing results presented in literature show that up to 100 km from coastal areas, 5G terrestrial systems can be used for control of autonomous ships, while for the further distances, satellite component of the integrated system should be used, [27].

IoT services for maritime industry in the coastal areas, up to 30 km from the coast, can be served by LoRa technology, which is representative of the LPWANs, [7] . LPWAN technologies are focused on low data rate communications with long ranges and high energy efficiency, which is requirement of the most IoT applications in maritime industry. LoRa is already implemented in some areas for tracking the small vessels in port and coastal areas and to collect data from smart buoys and moored platforms. Further research should be focused on testing this technology with different bandwidths, modulations and in harsh environmental conditions in order to obtain useful results for future projects and installations at seas.

REFERENCES

[1] https://iot-analytics.com/state-of-the-iot-update-q1-q2-2018-number-of-iot-devices-now-7b/

[2] Sanchez-Iborra, R., G. Liaño, I., Simoes, C., Couñago, E., F. Skarmeta, A.: Tracking and Monitoring System Based on LoRa Technology for Lightweight Boats, Electronics 2019, 8, 15; DOI:10.3390/electronics8010015.

[3] Xu, G., Shi, Y., Sun, X. and Sen, W., Internet of Things in Marine Environment Monitoring: A Review, Sensors, April 2019.

[4] De Sanctis, M., Cianca, E., Araniti, G., Bisio, I., Prasad, R.: Satellite Communications Supporting Internet of Remote Things, IEEE Internet of Things Journal, 2327-4662 (c) 2015 IEEE; DOI:10.1109/JIOT.2015.2487046.

[5] Höyhtyä, M., Ojanperä, T., Mäkelä, J., Ruponen, S., Järvensivu, P.: Integrated 5G satellite-terrestrial systems: Use cases for road safety and autonomous ships, 23rd Ka and Broadband Communications Conference (KaConf), Trieste, Italy, October 2017.

[6] Satellite communication services: An integral part of the 5G Ecosystem, EMEA Satellite Operators Association – ESOA, www.esoa.net.

[7] Petäjäjärvi, P., Mikhaylov, K., Pettissalo, M., Janhunen, J., Iinatti, J.: Performance of a low-power wide-area network based on LoRa technology: Doppler robustness, scalability, and coverage, International Journal of Distributed Sensor Networks, 2017, Vol. 13(3), DOI:10.1177/1550147717699412.

[8] Stankovic, J. A.: Research Directions for the Internet of Things, IEEE Internet of Things Journal, vol. 1, no. 1, Feb 2014.

[9] Kadowaki, N.: The Prospect of Satellite Communications and 5G Integration, National Institute of Information and Communications Technology (NICT), BroadSky Workshop, October 2018.

[10] Mukherjee, S., De Sanctis, M., Rossi, T., Cianca, E., Ruggieri, M., Prasad, M.: Mode Switching Algorithms for DVB-S2 Links in W Band, IEEE Globecom 2010, Miami (Florida), 6-10 December 2010.

[11] Chenine, M., Nordstrom, L.: Modeling and Simulation of Wide-Area Communication for Centralized PMU-Based Applications, IEEE Transactions on Power Delivery, vol. 26, no. 3, July 2011, DOI:10.1109/TPWRD.2011.2106805.

[12] Bisio, I., Marchese, M.: Efficient Satellite-Based Sensor Networks for Information Retrieval, IEEE Systems Journal, vol. 2, no. 4, December 2008, DOI:10.1109/JSYST.2008.2004850.

[13] Bacco, M., Colucci, M., Gotta, A.: Application Protocols enabling Internet of Remote Things via Random Access Satellite Channels, IEEE ICC 2017, Paris, France, 21-25 May 2017, DOI:10.1109/ICC.2017.7997292.

[14] Casini, E., De Gaudenzi, R. R. Herrero, O.: Contention Resolution Diversity Slotted ALOHA (CRDSA): An Enhanced Random Access Scheme for Satellite Access Packet Networks, IEEE Transactions on Wireless Communications, vol. 6, no. 4, pp. 1408-1419, April 2007, DOI:10.1109/TWC.2007.348337.

[15] Kawamoto, Y., Nishiyama, H., Fadlullah, Z. M., Kato, N.: Effective Data Collection Via Satellite-Routed Sensor System (SRSS) to Realize Global-Scaled Internet of Things, IEEE Sensors Journal, vol. 13, no. 10, October 2013, DOI:10.1109/JSEN.2013.2262676.

[16] Kumar, H. S. R., Kamal, A.: Performance Modeling and Simulation Studies of MAC Protocols in Sensor Network Performance, 7th International Wireless Communications and Mobile Computing Conference (IWCMC), pp. 1871 – 1876, 4-8 July 2011.

[17] ETSI TS 101 545-3: Digital Video Broadcasting (DVB); Second Generation DVB Interactive Satellite System (DVB-RCS2); Part 3: Higher Layers Satellite Specification, 2012.

[18] GSMA: 5G Spectrum: Public Policy Position, November 2016.

[19] European Commission, Radio Spectrum Policy Group: Strategic roadmap towards 5G in Europe: Opinion on spectrum related aspects for next-generation wireless systems (5G), November 2016.

[20] Corici, M., Kapovits, A., Covaci, S., Geurtz, A., Gheorghe Pop, I. D., Riemer, B., Weber, A.: Assessing satellite-terrestrial integration opportunities in the 5G environment, ARTES 1 INSTINCT White paper, September 2016.

[21] Shafi, M., Molisch, A. F., Smith, P. J., Haustein, T., Zhu, P., De Silva, P., Tufvesson, F., Benjebbour, A., Wunder, G.: 5G: A tutorial overview of standards, trials, challenges, deployment, and practice, IEEE Journal on Selected Areas in Communications, vol. 35, pp. 1201-1221, June 2017, DOI: 10.1109/JSAC.2017.2692307.

[22] Tehrani, R. H., Vahid, S., Triantafyllopolou, D., Lee, H., Moessner, K.: Licensed spectrum sharing schemes for mobile operators: A survey and outlook, IEEE Communications Surveys & Tutorials, vol. 18, pp. 2591–2623, Fourth Quarter 2016, DOI:10.1109/COMST.2016.2583499.

[23] Zolich, A., Palma, D., Kansanen, K., Fjørtoft, K., Sousa, J., Johansson, K. H., Jiang, Y., Dong, H., Johansen, T. A.: Survey on Communication and Networks for Autonomous Marine Systems, Journal of Intelligent & Robotic Systems, Volume 95, Issue 3–4, pp 789–813, September 2019, DOI:https://doi.org/10.1007/s10846-018-0833-5.

[24] The Maritime IoT landscape in the next decade, https://www.rivieramm.com/opinion/opinion/the-maritime-iot-landscape-in-the-next-decade-23759, 6 August 2018.

[25] Höyhtyä, M., Huusko, J., Kiviranta, M., Sohlberg, K., Rokka, J.: Connectivity for autonomous ships: Architecture, use cases, and research challenges, International Conference on Information and Communication Technology Convergence (ICTC) 2017, Jeju, South Korea, October 2017, DOI:10.1109/ICTC.2017.8191000.

[26] Ahvenjarvi, S.: The human element and autonomous ships, International Journal on Marine Navigation and Safety of Sea Transportation, vol. 10, pp. 517–521, September 2016, DOI:10.12716/1001.10.03.18.

[27] Jennings, A.: Modern Maritime Communications, ITU World Radiocommunication Seminar 2016, Geneva, Switzerland, 12-16 December 2016.

[28] Richart, M., Baliosian, J., Serrat, J., Gorricho, J. L.: Resource Slicing in Virtual Wireless Networks: A Survey, IEEE Transactions on Network and Service Management, vol. 13, Issue: 3, pp. 462–476, September 2016, DOI:10.1109/TNSM.2016.2597295

[29] Laursen, W.: Machine to Machine in the Container Supply Chain, https://www.maritime-executive.com/features/machine-to-machine-in-the-container-supply-chain, August 2016.

[30] Michelin tracks inter-continental sea-freight flows with an IoT-based solution developed with Sigfox France and Argon Consulting, https://www.sigfox.com/en/news/michelin-tracks-inter-continental-sea-freight-flows-iot-based-solution-developed-sigfox-france, Press release, 24 May 2018.

[31] Wireless Maritime Services: Increasing Your Connectivity on Board, https://www.seatradecruiseglobal.com/wireless-maritime-services-increasing-your-connectivity-board, 15 March 2019.

[32] Wingrove, M.: 5G and LEO satellites to deliver IoT to shipping, https://www.rivieramm.com/news-content-hub/5g-and-leo-satellites-to-deliver-iot-to-shipping-23308, 20 September 2018.

[33] Wendt, T., Volk, F., Mackensen, E.: A benchmark survey of long range (LoRaTM) spread-spectrum-communication at 2.45 GHz for safety applications, 2015 IEEE 16th Annual Wireless and Microwave Technology Conference (WAMICON), Cocoa Beach, USA, pp.1–4, 13–15 April 2015, DOI:10.1109/WAMICON.2015.7120312

[34] LoRa-Alliance. Available online: https://www.lora-alliance.org/

[35] Nolan, K. E., Guibene, W., Kelly, M. Y.: An evaluation of low power wide area network technologies for the Internet of Things, 2016 International Wireless Communications and Mobile Computing Conference (IWCMC), Paphos, Cyprus, pp.439–444, 5–9 September 2016, DOI:10.1109/IWCMC.2016.7577098

[36] Sanchez-Iborra, R., Cano, M. D.: State of the Art in LP-WAN Solutions for Industrial IoT Services, Sensors 2016, 16(5), 708, DOI: https://doi.org/10.3390/s16050708

[37] LoRaWAN® Specification v1.1, https://lora-alliance.org/resource-hub/lorawanr-specification-v1

CORRELATION ANALYSIS OF MARITIME TRAFFIC

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Summary

This paper presents an analysis of the dynamics of maritime traffic in the Republic of Croatia and also determine, compare and analyse the position of the Republic of Croatia in EU maritime transport. The purpose of this paper is to analyse the correlation between selected factors on the one hand and maritime traffic in Croatia on the other. The analysis includes the following variables: gross weight of seaborne goods in EU ports, gross weight of seaborne goods in Croatian ports, seaborne trade in EU, population of the Republic of Croatia, population of the EU, number of seaborne passengers in Croatian ports, number of seaborne passengers in EU ports, GDP in EU, GDP in Croatia. Quantitative analysis was carried out based on the data gathered from Eurostat and Croatian Bureau of Statistics. The data collected were analysed using the correlation analysis method. The results show that there is a relatively weak or mild correlation between the observed indicators, but most often it is not statistically significant. However, based on the obtained, the results can be summarized as follows: There are statistically significant relationships between number of seaborne passengers in Croatia and population in EU; between number of seaborne passengers in Croatia and population in Croatia; and between number of seaborne passengers in Croatia and GDP of Croatia. There is a statistically significant relationship between gross weight of seaborne goods in Croatian ports and seaborne trade in EU.

Keywords: correlation analysis, maritime traffic, Croatia

1. INTRODUCTION

The Republic of Croatia is traditionally a maritime country. Croatian seaports have an economic potential based primarily on a favourable geographic position. The main comparative advantage of Croatian seaports compared to other ports of the European Union is the fact that the Adriatic see reaches far inland into the continent which ensures the shortest and cheapest transport connection for countries located behind Croatia to the east Mediterranean, and via the Suez Canal to Asian and East-African countries.

Roles of ports have major impacts on the economy of the country. The impacts could have positive and negative effects. Positive are related to economic growth, GDP. Also, ports create indirect and direct jobs, and one of the main points is the increase of demand for employment derived from related activities and industries. Negative effects are mainly related to environment, its pollution and to traffic congestion. Ports play an essential role in term of transporting freight and people in a maritime field. Therefore, they act as the linkage gates between distinct continents.

The advantages of maritime transport in relation to road and rail transport are: lower prices, higher transport transportation capacity, their flexibility for transporting more types of cargo, security and less pollution of the environment. The main disadvantage is the slowness and the high cost of means of transport. Maritime traffic is one of the safest, most ecologically and financially most affordable forms of transport. Maritime traffic is 3.5 times cheaper than rail and 7 times cheaper than road transport.

The intensity, direction, structure and dynamics of maritime goods and passenger flows are indicators of world traffic concentration, pointing to the importance and position of the world's production and consumption centres, i.e. the centre of economic development. For this reason, the value of the results obtained by analysing maritime traffic indicates the purpose of their monitoring.

2. LITERATURE REVIEW

In recent decades, a major contribution to the world economy has made by the maritime industry. The "Maritime Review by 2015" reported by the United Nations Conference on Trade and Development (UNCTAD) shows that nearly 80% of global commodity trade in volume terms was completed through ports and maritime transport routes [1]. Maritime traffic is of great importance to the state itself. It not only ensures the import of scarce resources needed for production, but also facilitates the export of excessive resources. Maritime transport is also a key to economic globalization [2]. The most important mode of transport in international trade has become container transport. That's new window for the development of foreign economic relationship and trade. Worldwide container port throughput increased from 36 million TEU in 1980 to 614 million TEU in 2017 and forecasts point to more than 800 million TEU in 2017 [3].

The maritime transport industry has undergone structural changes such as restructuring shipping networks by deploying larger vessels with a smaller number of ports of call (Bang et al, 2012. [4]; Wang et al, 2014. [5]).

Ports are important, but also sensitive, part of maritime transport. Results of the numerous reports about ports all around the world clearly indicate that ports are a vital part of a country's economy. The growth of the port will, for sure, strengthen the country's economy, as per Sleeper (2012) [6]. The development and growth of ports lead to larger trade activities, increased supply, greater foreign exchange reserves and reduced prices for commodities as a whole. Improvement in the port infrastructure has shown very good reflections in the GDP in lots of cases discussed. Sleeper (2012) determined that there is a positive trend in relationship the greater number of highly-acclaimed ports in the country, the higher the GDP.

Ports are, therefore, a key component of the logistics chain. Their operation has a direct effect on relevant economic variables such as export competitiveness and final import prices, thus affecting economic development according to [7] Tovar et al.

In scientific literature maritime passenger transport is not significantly present. Among several authors are [8] Vaggelas and Pallis who conducted a survey among top 20 European passenger ports in order to identify and classify different services provided in passenger ports, [9] Asić who analysed passenger ports efficiency in the Republic of Croatia and Luković [10] who analysed cruise industry with emphasis on cruise operators and cruise companies

3. METHODOLOGY

The study relied heavily on secondary data obtained from the Croatian National Bureau of Statistics (www.dzs.hr) and from the Eurostat database (http://ec.europa.eu/eurostat). All the necessary data was collected for the period from 2006 to 2016.

The analysis includes the following variables: gross weight of seaborne goods in EU ports (in million tons), gross weight of seaborne goods in Croatian ports (in million tons), population of the Republic of Croatia (in 1000), population of the EU (in million), number of seaborne passengers in Croatian ports (in 1000), number of seaborne passengers in EU ports (in 1000), GDP in EU and GDP in Croatia (1000 €).

To determine the degree of correlation between the two observed variables (selected factors and indicators of maritime traffic in Croatia) the correlation method analysis was used.

4. DYNAMICS OF MARITIME TRANSPORT

The strategy on maritime policy, the fundamental document based on predicting and directing Croatian maritime economy, was highlighted:

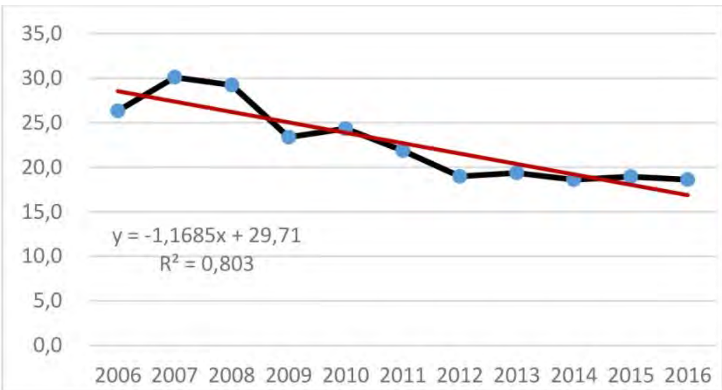
Considering the indicated statistics and the economic situation in the Republic of Croatia and its surroundings, but also the fact that investments in the modernisation of the port sector have been made, objectives have been set for the coming period, the achievement of which is necessary for the port sector to respond to the needs of the EU market and become competitive on it. We anticipate an increased turnover in both passenger and cargo traffic after achieving these objectives, which will indirectly influence the increase of the income, or in other words, share of the port sector in the gross domestic product of the Republic of Croatia [13]. Due to the above, it is necessary to determine, compare and analyze the position of the Republic of Croatia in EU maritime transport.

4.1. Dynamics of seaborne goods transport in Croatia and EU

Since more than 65% of the total international trade in goods is carried by sea, intensity, direction, structure and dynamics of marine cargo flows are indicators of concentrations of world traffic. These indicators point to the importance and positioning of the world's centers of production and consumption, i.e. the centers of economic development. Therefore, the value of the results obtained by analyzing the mentioned indicators on the state of the maritime commodity flows, also shows the purpose of their monitoring.

The majority of cargo traffic in Croatian ports is carried out in the Rijeka and Ploče ports, totaling close to 90% of the total cargo traffic of all Croatian ports of exceptional economic significance and making them the leading cargo ports of the Republic of Croatia.

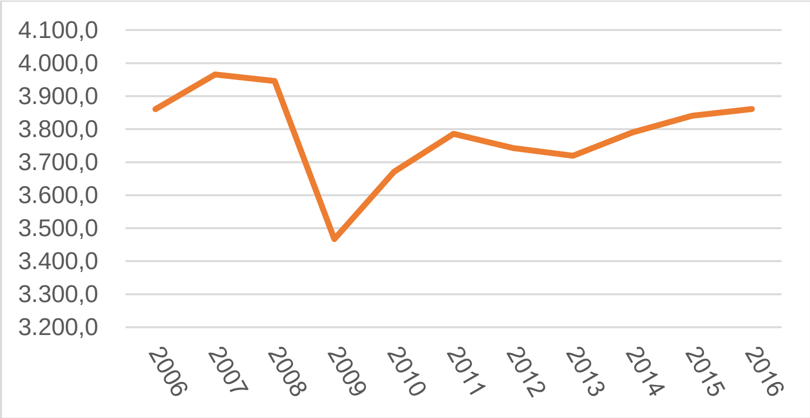
This paper wants to determine what is trend of maritime freight traffic from 2006 to 2016 and whether the trends of the EU and Croatia are following one another. From Graph 1 it can be concluded that commodity maritime traffic in Croatia has a linear trend and a negative inclination. Coefficient b = -1.1685 shows that in one year commodity turnover decreases on average by 1.1685 million tones, which are alarming data and warnings to the Government of Croatia that must take decisive steps to stop that negative trend. The coefficient of determination r^2 = 0.803 shows that the linear trend is representative and can be used for the forecast of future movements.



Graph 1 Gross weight of seaborne goods handled in Croatian ports, 2006-2016 (in million tonnes)

Source: Author’s calculation

The needs for maritime transport are determined by the number of inhabitants and the level of economic activity as the basic generator of traffic demand. As far as intra-EU trade and trade with countries bordering the EU is concerned, more than 40% of all goods are transported by sea, by short-haul transport, i.e. short sea shipping. Graph 2 shows the volume of goods transported in the EU in the period from 2006 to 2016 in thousands of tons. The linear trend does not reflect the display of wholly-transported goods.



Graph 2 Gross weight of seaborne goods handled in all EU-ports, 2006-2016 (in million tonnes)

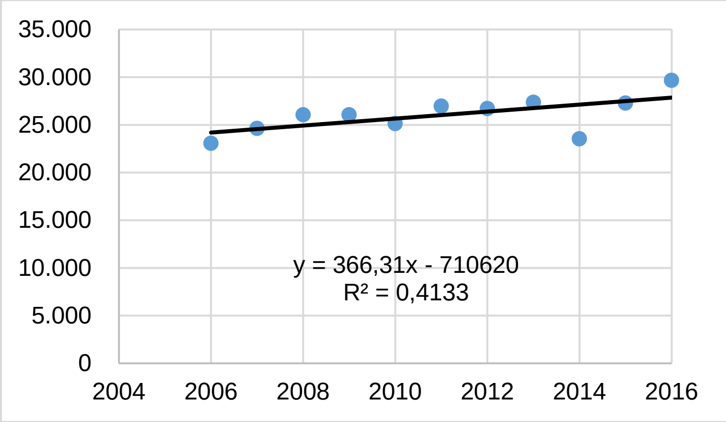
Source: According Eurostat (online data code:mar_mg_aa-cwhd)

From the graph 2 it can be clearly seen that in the crisis years the quantity of carried goods has fallen. The reason for the above is that in this period falls demand for products, and thus falls any need for the goods. In contrast to the negative trend of maritime freight transport in the Republic of Croatia from 2013 the EU's maritime freight transport has a positive trend.

4.2. Dynamics of passenger maritime transport in Croatia and EU

The majority of passenger maritime transport in Croatia is carried out in the Split and Zadar ports, and Dubrovnik is the port with the majority of traffic of cruising vessels. The attractiveness of the coastal area, membership in the European Union, the expansion of the European Union to neighboring countries and funding opportunities from European Union funds are the factors that should be utilized.

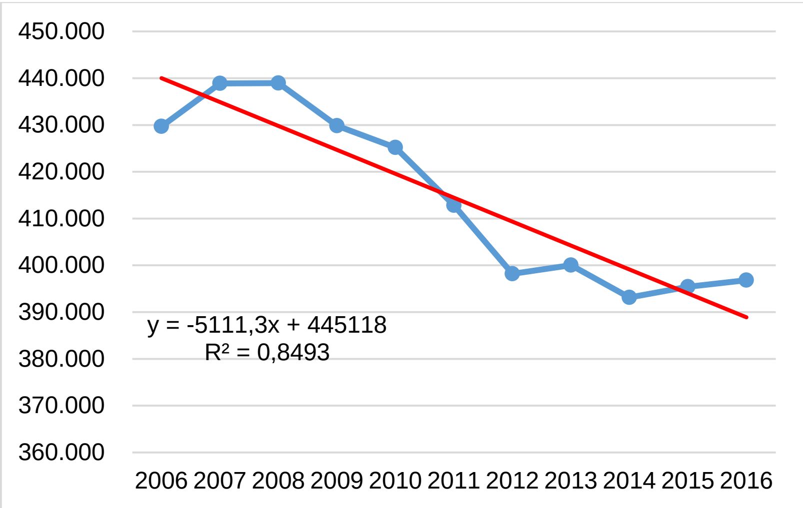
From Graph 3 it can be concluded that number of seaborne passenger in Croatian ports has a linear trend and, unlike maritime seaborne goods traffic, is positive. In one year, the total number of seaborne passengers is linear average increase by 366.31 thousand. The representability of the model is $r^2 = 0.4133$, which indicates, that in using this linear trend, to explain the dynamics of passenger movements we have to be careful. In planning maritime passenger traffic, we cannot rely solely on it, but on other analyses and models as well.



Graph 3 Number of seaborne passengers embarked and disembarked in Croatian ports, 2006-2016 (in 1000)

Source: Author's calculation

As with seaborne goods traffic, an analysis of the number of seaborne passengers in EU maritime transport was done and shown on graph 4.



Graph 4 Number of seaborne passengers embarked and disembarked in EU ports, 2006-2016 (in 1000)

Source: Author's calculation

In contrast to the trend in the number of seaborne passengers in Croatia, in EU ports the total number of seaborne passengers is declining, which means that maritime passenger traffic in Croatia does not track trends in the EU. The reasons for its growth need to be sought in linking maritime traffic to other indicators. The trend of the number of seaborne passengers in the EU is the linear function shown on graph 4, which is a negative slope and shows that in a year the total number of seaborne passengers in EU ports is average reduced by 5111.3 thousand. The linear function whose equation is given on the graph is representative, $r^2 = 0.8493$ and can be used as a forecasting model.

5. CORRELATION ANALYSIS

5.1. Results of correlation analysis for the seaborne goods

The results of correlation the GDP growth rate in the Republic of Croatia, GDP growth rates in the EU, maritime transport of goods in EU ports with maritime transport of goods in ports of Croatia are shown in Table 1. The Pearson coefficient of linear correlation was used to establish the correlation between the observed variables. The significance of the coefficient of correlation was estimated at the significance level of 5% i.e. $p = 0.05$.

The representativeness of the obtained regression model was checked by using the coefficient of determination R^2 and regression coefficient of variation V.

Table 1 Results of correlation analysis for the seaborne goods of the Republic of Croatia

Variable	Coefficient of correlation (r)	Reliability (p)
GDP of the Republic of Croatia	0,051	0,889
GDP of the EU	0,024	0,944
Seaborne goods in EU	0,346	0,297
Seaborne trade	-0,840	0,001

Source: Author's calculation

The results in Table 1 indicate that the correlation between the GDP of the Republic of Croatia and the maritime transport of seaborne goods in the Republic of Croatia, the correlation between the GDP of EU and maritime transport in the Republic of Croatia as well as the seaborne goods of EU and Republic of Croatia are small and statistically not significant ($p \geq 0.05$). Seaborne trade and maritime transport of seaborne goods in Croatia are highly correlated but correlation is negative.

5.2. Results of correlation analysis for the seaborne passengers

In Table 2 are results of the analysis of correlation of the next variables: GDP of EU, GDP of the Republic of Croatia, population of the Republic of Croatia, population of EU, seaborne passengers of EU with seaborne passengers of the Republic of Croatia.

Table 2 Results of correlation analysis for the seaborne passengers of the Republic of Croatia

Variable	Coefficient of correlation (r)	Reliability (p)
Population RC	-0,682	0,0431
Population EU	0,655	0,029
GDP of the RC	0,604	0,024
GDP of the EU	0,002	0,498
Seaborne passenger EU	-0,44578	0,169

Source: Author's calculation

The correlation coefficients in Table 2 show that the correlations between the population of the Republic of Croatia and the passenger traffic in RC, between the population of the EU and the passenger traffic in the Republic of Croatia and between GDP of the RC and the passenger traffic in the RC are statistically significant ($p \leq 0.05$).

6. CONCLUSION

Based on the analyses and interpretations of the appropriate data, findings from the results of the study are discussed as follows:

Firstly, the study revealed that there isn't correlation between gross weight of seaborne goods handled in Croatia and gross weight of seaborne goods handled in EU ports and GDP in EU. This implies that future researches should examine the role of other factors.

Secondly, the study revealed that there isn't correlation between the number of seaborne passengers in Croatia and number of seaborne passengers in EU ports and GDP in EU.

According to the findings, it can be concluded that: (a) there is a statistically significant relationship between GDP in Croatia and the number of seaborne passengers in Croatia, (b) there is a statistically significant relationship between population in Croatia and the number of seaborne passengers in Croatia, (c) there is a statistically significant relationship between population in EU and the number of seaborne passengers in Croatia and (d) that there is statistically significant correlation between gross weight of seaborne goods handled in Croatia and seaborne trade.

Finally, the study also revealed that gross weight of seaborne goods in Croatia has a linear trend with a negative slope and that in one year the gross weight of seaborne goods average decreases by 1.1685 million tonnes, which are alarming data for Republic of Croatia, while passenger maritime traffic in Croatia has a positive linear trend.

REFERENCES

[1] Lingshan, C.; Xiang, X.: Ping Z.; Xiaotian Z.: Analysis on Port and Maritime Transport System Researches, Journal of Advanced Transportation, 2018, Vol. 2018, https://doi.org/10.1155/2018/6471625

[2] W. Shi and K. X. Li:Themes and tools of maritime transport research during 2000-2014, Maritime Policy & Management, 2017, Vol. 44, No. 2, pp. 151–169.

[3] Annual Review of Global Container Terminal Operators, Drewry - Shipping Consultants, London, 2016.

[4] Bang, H.-S.; Kang, H.-W.; Martin, J.; Woo, S.-H.: The impact of operational and strategic management on liner shipping efficiency: A two-stage DEA approach, 2012, Maritime Policy & Management 39 (7), pp. 653–672.

[5] Wang, G. W.; Woo, S. H.; Mileski, J.: The relative efficiency and financial risk assessment of shipping companies, 2014, Maritime Policy & Management 41 (7), pp. 651–666.

[6] Sleeper, D. M.: Port Significance: Contributions to Competitiveness in Latin America and Asia, 2012, Journal for Global Business and Community, Vol. 3, Issue 1, pp. 22-28.

[7] Tovar,B.; Jara-Diaz, S.; Trujillo,L.: Econometric Estimation of Scale and Scope Economies within the Port Sector: A Review, CCRP Working Paper No 7,Centre for Competition and Regulatory Policy (CCRP), DAEA, Universidad de Las Palmas de Gran Canaria

[8] Vaggelas, G. K.; Pallis, A. A.: Passenger ports: services provision and their benefits, 2010, Maritime Policy & Management, Vol. 37, No. 1, pp. 73-89. http://dx.doi.org/10.1080/03088830903461209

[9] Asić, A.: Analysis of passenger port efficiency in the Republic of Croatia, 2010, Pomorstvo, Vol. 25, No. 1, pp. 71-86.

[10] Luković, T.: Analysis of the development of world and Croatian cruising, 2008, International Journal of Maritime Science & Technology „Our Sea", Vol. 55, No. 5-6, pp. 233-248.

[11] Pupavac D.; Plazibat V.; Krčum M.: Modelling Transport Demands in Maritime Passenger Traffic, 2015, Naše More: znanstveno-stručni časopis za more i pomorstvo, Vol.62, No.1, pp.8 – 12.

[12] Cho H.; Kim S.: Examining Container Port Resources and Environments to Enhance Competitiveness: A Cross-Country Study from Resource-Based and Institutional Perspectives, 2015, The Asian Journal of Shipping and Logistics, Vol. 31, Issue 3, pp. 341-362.

[13] http://www.csamarenostrum.hr/userfiles/files/Nacion%20zakon%20engl/MDIMPSRC.pdf_MARITIME DEVELOPMENT AND INTEGRATED MARITIME POLICY STRATEGY OF THE REPUBLIC OF CROATIA FOR THE PERIOD FROM 2014 TO 2020

RESEARCH OF CARGO SEAPORTS DEVELOPMENT IN THE RUSSIAN FEDERATION IN THE CONTEXT OF PORT BASINS

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Summary

Seaports play a key role in the development of cargo turnover and international trade. About 60% of the Russian Federation foreign trade cargoes are handled in seaports. Improving the quality of seaports, which serve the increasing capacity of global freight traffic, is an important task for those countries, involved in the transportation of goods by sea. The article presents analyses of the development of stevedoring industry in Russia in the context of port basins. The statistical base covers a 16-year period. The research methods are statistical analysis and econometric modeling. The result of the study is an economic and geographical model of cargo transshipment in the Russian Federation, distributed over the sea basins. The model is built taking into account the geographical localization of certain types of cargoes, caused by the location of production facilities and peculiarities of logistics routes linking shippers and consignees. The model reflects the relationship between the development of the stevedoring industry and the regional economy. Based on the constructed model, conclusions about the presence of development prospects and constraints typical for each analyzed port were made. Among the limiting factors for the development of the stevedoring industry in Russia, the lack of rapid development of railway infrastructure and insufficient depth of channels in the waters of seaports are highlighted. Tools to overcome these problems have been proposed.

Keywords: stevedoring industry, seaports, sustainable development

1. INTRODUCTION

During 2005-2018 growth transfer loads capacity in the Russian Federation seaports approximately corresponded to the growth of the international sea trade, and since 2014, despite negative dynamics of the Russian Federation GDP, even exceeded a world indicator [17]. Besides, growth transfer loads capacity advanced growth of the Russian export in the ports of the Russian Federation in general [19].

Among the positive trends in the development of the stevedoring industry in Russia is the fact that, according to the results of the world ports rating compiled by Alphainer, the port of St. Petersburg has become one of the world's container ports. In 2018, the port complex of St. Petersburg exceeded 2.13 million TEU and occupied the 84th line of the Alphainer rating [1].

Generally, during 2005-2018 the stevedoring industry of Russia showed continuous positive dynamics on volumes of transportation of goods. For this period annual average rate of gain is 5.5% [2]. The transfer capacity of loads in seaports of the Russian Federation grew twice, it was from 407 to 816 million t (see Figure 1). Figure 1 shows the dynamics of changes in freight turnover over the period 2005-2018. with a breakdown of the total for the 5 sea basins of Russia: the Arctic Sea Basin, the Baltic Sea Basin, the Azov-Black Sea Sea Basin, the Caspian Sea Basin and the Far Eastern Sea Basin. All of them, with the exception of the Caspian Sea Basin, show a steady growth in turnover throughout the entire analyzed period.

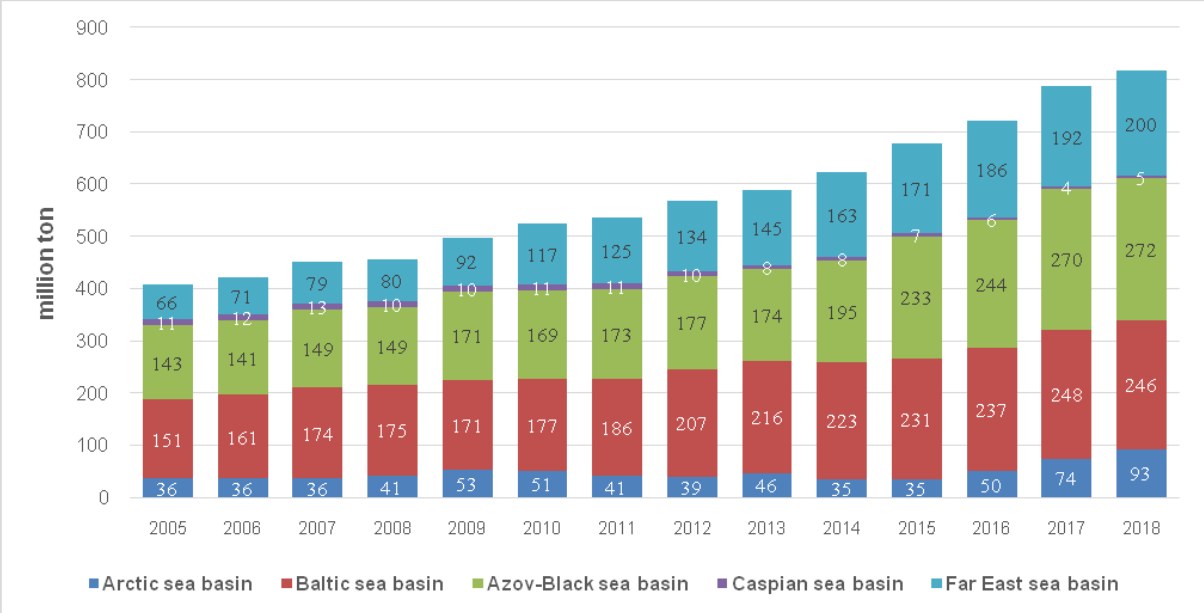


Figure 1 Dynamics of transfer loads in ports for the Russian sea basins during 2005-2018, mln t

Source: Own processing

However, according to many experts, these rates are not enough and it is necessary to develop a set of measures that would ensure even more rapid development of the stevedoring industry [14]. The complexity of the development of the stevedoring industry in Russia lies in the fact that it is multi-regional and multi-territorial. It includes port complexes of 5 marine basins, there are direct access to 3 oceans: the Pacific Ocean, the Atlantic Ocean and the Arctic Ocean. Therefore, when developing a program for the development of the stevedoring industry, it is necessary to take into account completely different climatic, logistical, technical, economic conditions for the functioning of seaports, their historically established trading traditions and cargo connections with foreign countries. So, J. Chen, A. Liu and their colleagues proved that the macroeconomic environment has a great influence on the concentration distribution of regional container ports. At the same time, economic cyclicality can accelerate the concentration of ports, and economic counter-cyclicality will cause port decentralization [4, p.61273]. In this regard, the importance of regional programs to support the development of port infrastructure is growing, as noted by researchers from many countries in relation to various ports in leading countries of the world.

Features of the formation of the port development strategy in the context of globalization were studied using examples from the leading ports of the world. So, J. Lam analyzed the change in the development of the sea transshipment hub for the example of the port of Singapore [12], and also, together with W. Zhang he carried out an empirical analysis of the evolution of sea clusters in terms of the port development - cases from London and Hong Kong [21]. D.W. Song identifies a special type of "hub ports" in the logistics era [15].

At present, the influence of competition between maritime companies on changes in port management and strategic decision-making in the field of state and regional policy is being actively studied. For example, G. Knats analyzed this influence on public policy in the United States [11]. G. Wilmsmeier and J.

Monios investigated the influence of the institutional structure and agency in managing the spatial diversification of the port system evolution in Latin America [20], and P.W. de Langen and L.M. van der Lugt studied the results of institutional reforms of the port authorities in the Netherlands to create port development companies [6].

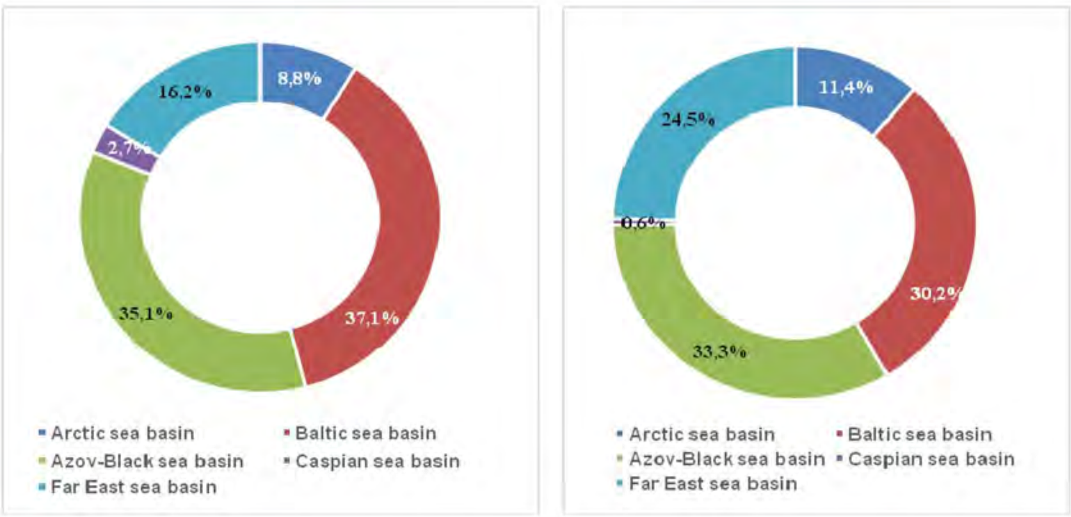
A large number of recent studies have been devoted to the development of various mathematical and econometric models for describing various factors in the development of ports and their interconnections with external subjects. For example, the studies of J. Debris and N. Raimbo are devoted to the analysis of the port-city relationship in two European countries [7].

M. Dotoli, N. Epikoko, M. Falagario and G.Kavone propose to use the model of temporary Petri nets to assess the performance of intermodal freight transport terminals [8]. Halim, R.A., Kwakkel, J.H. and Tavasszy, L.A. developed a strategic model of port-domestic freight distribution networks [10], and Chen, H., Kullinan, K. and Liu, N. proposed a model for measuring the sustainability of the port-internal network of container traffic [3]. L.S. Nguyen and T. Nottebumusing the example of Vietnam, applied a multi-criteria approach to the location of dry ports in developing countries [13]. W. Zhuang, M. Lo and X. Fu used the game theory toolkit to analyze port specializations using the example of the Chinese port industry [22]. L. Song and colleagues used a game-theoretical approach for modeling competitions in a maritime supply chain [16].

These and other conceptual and methodological developments were taken into account when conducting this study.

2. THE STATISTICAL ANALYSIS OF THE STEVEDORING INDUSTRY DEVELOPMENT IN RUSSIA

Most of all loads are processed in Azov-Black sea and Baltic basins, but the share of ports of these basins in the total amount of loads transfer is reduced (see Figure 2) [9, 18]. For the considered period the share of loads transfer for ports of the Arctic and Far East basins considerably increases.

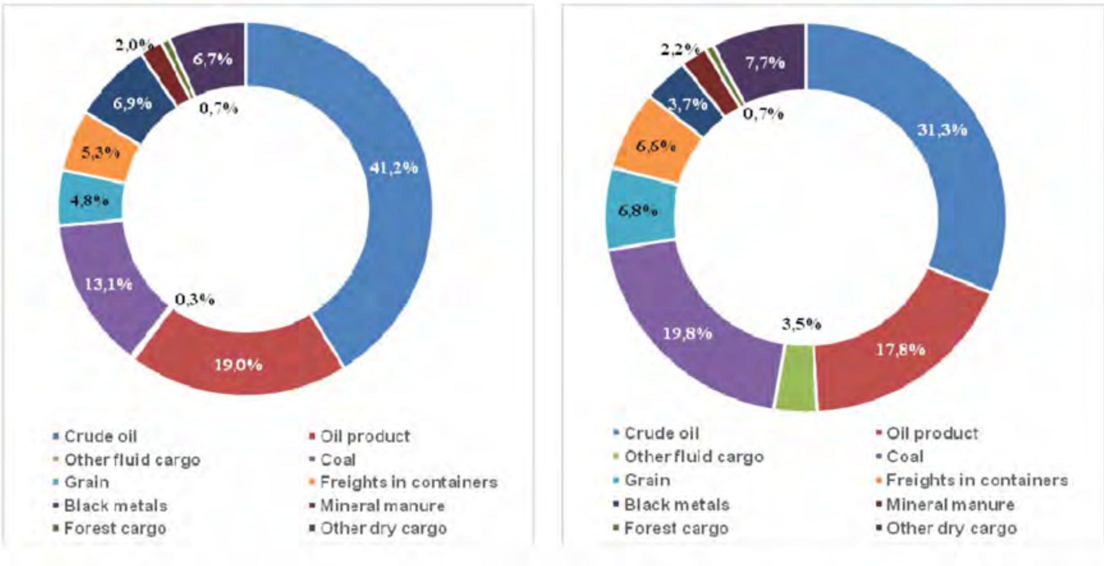


Total in 2005 Total 2018

Figure 2 Structure of loads transfer in ports for the Russian sea basins for 2005 and 2018

Source: Own processing

We analyzed structure of freights transfer in a section of dry and bulk freights. In 2018 fluid cargo made 429 million t (52.6%), and dry – 387 million t (47.4%). Among fluid cargo it is most of all processed crude oil (255.4 million t) and oil products (145.1 million t), and among dry – coal (161.4 million t), grain (55.7 million t), freights in containers (53.6 million t) (see Figure 3).



Total in 2005 Total in 2018

Figure 3 Structure of loads transfer in the Russian ports by types of loads for 2005 and 2018

Source: Own processing

2.1. Research of localization of separate types freights in a sea basins section

The analysis structure of loads transfer in ports for the Russian sea basins allowed to reveal accurate localization of separate types loads in a sea basins section. Therefore, the Arctic sea basin specializes in coal transfer (76.8%) and mineral fertilizers (15.3%), other loads make only 7.9% (see Figure 4).

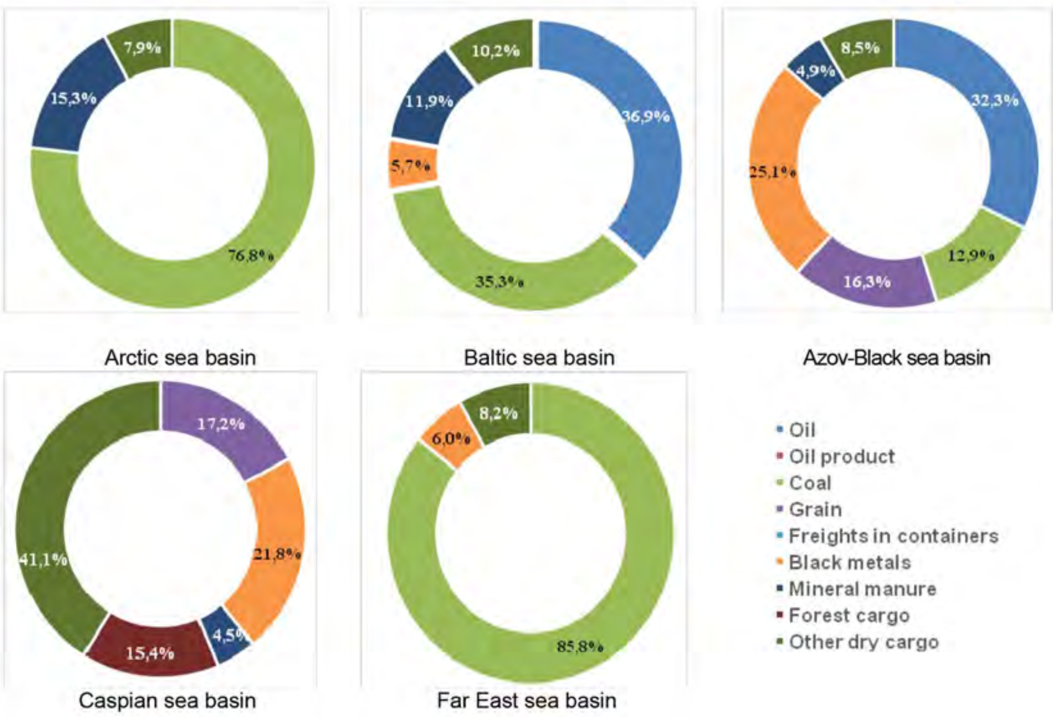


Figure 4 Structure of loads transfer in ports for the Russian sea basins for types of loads for 2018

Source: Own processing

The Baltic sea basin specializes in coal transfer (35.3%) and oil loads (36.9%), other loads make 27.8%. The Azov-Black sea basin specializes in transfer of oil loads (32.3%), ferrous metals (25.1%), grain (16.3%), other loads make 26.3%. The Far East sea basin specializes in coal transfer (85.8%), other loads make 14.2%. The Caspian sea basin has no accurately expressed specialization.

So, Russian seaports generally specialize in transfer of raw material resources (coal and oil loads).

3. RESEARCH

3.1. Research factors influencing development of seaports

For the research of the infrastructure and regional factors having an impact on development of seaports, ports were grouped in regions of presence. For component analysis the following factors were selected:

- infrastructure:
- area of the territory of seaport, hectare (x1);
- area of the water area of seaport, km (x2);
- number of moorings, unit (x3);
- length of the mooring front, item of m (x4);

- regional:
- operational length of railway tracks, km (x5);
- density of railway tracks, km (x6);
- extent of internal waterways, km (x7);
- extent of highways, km (x8);
- the capacity of the shipped self-produced goods, million rubles (x9).

For identification of influence of the considered factors on development of seaports the correlation matrix (see Table 1) was constructed [5].

Table 1 Correlation matrix the analysis of factors of Russian seaports development

	y	x1	x2	x3	x4	x5	x6	x7	x8	x9
y	1,00									
x1	0,58	1,00								
x2	0,15	-0,06	1,00							
x3	0,51	0,50	0,35	1,00						
x4	0,62	0,54	0,30	0,98	1,00					
x5	0,66	0,41	0,19	0,10	0,20	1,00				
x6	0,07	0,20	0,29	0,29	0,26	-0,28	1,00			
x7	-0,11	0,08	0,42	-0,27	-0,27	0,26	-0,26	1,00		
x8	0,59	0,08	0,09	0,24	0,33	0,61	-0,20	-0,19	1,00	
x9	0,07	0,19	0,35	0,20	0,20	-0,22	0,62	0,34	-0,27	1,00

Source: Own processing

The second column of Table 1 shows the correlation coefficients between the resulting indicator y and the considered factors x1-x9, which show the strength of the relationship between the indicators. If the correlation coefficient is less than 0.4, then the correlation is weak, if it is from 0.4 to 0.7, then the correlation is substantial, if it is greater than 0.7, then the correlation is strong. If the correlation coefficient has a positive value, then the link is direct, if it has negative one, then the link is reverse. In the table, the correlation coefficient between y and x1, x3, x4, x5, x8 was 0.58, 0.51, 0.62, 0.66, 0.59, indicating a substantial correlation strength. The correlation coefficient between y and x2, x6, x7, x9 was 0.15, 0.07, -0.11, 0.07, suggesting weak correlation strength. According to Table 1, 5 factors have a significant effect: x1, x3, x4, x5, x8. The 3-11 columns of the table represent the correlation coefficients between the factors. If the correlation coefficient between factors is close to 1, the factors have a strong multicollineal correlation, and one of the factors needs to be excluded. The correlation coefficient between factors x3 and x4 is 0.98. Factor x3 is excluded from further investigation because it has a strong multicollineal relationship with factor x4. Estimation of the remaining factors shows no multicollinearity.

Give a detailed characteristic of the correlation coefficients between the resulting indicator y and the considered factors x1-x9, which are presented in the second column of Table 1. The calculated correlation coefficients and the relationship characteristic are presented in Table 2.

Table 2 Correlation analysis of influence of infrastructure and regional factors on seaports development

Indicator	Value	Characteristic
Correlation coefficient between the capacity of loads transfer and the area of the seaport territory	0,58	Correlation direct, considerable
Correlation coefficient between the capacity of loads transfer and the area of the seaport water area	0,15	Correlation direct, weak
Correlation coefficient between the capacity of loads transfer and the number of moorings	0,51	Correlation direct, considerable
Correlation coefficient between the capacity of loads transfer and mooring front long	0,62	Correlation negatively associated, considerable
Correlation coefficient between the capacity of loads transfer and operational length of railway tracks in the region	0,66	Correlation direct, considerable
Correlation coefficient between the capacity of loads transfer and density of railway tracks in the region	0,07	Correlation direct, weak
Correlation coefficient between the capacity of loads transfer and extent of internal waterways in the region	-0,11	Correlation negatively associated, weak
Correlation coefficient between the capacity of loads transfer and extent of highways in the region	0,59	Correlation direct, considerable
Correlation coefficient between the capacity of loads transfer and capacity of the shipped self-produced goods in the region	0,07	Correlation direct, weak

Source: Own processing

The correlation analysis allowed drawing a conclusion that four factors have significant effect on development of seaports in Russia: area of the territory of seaport (correlation coefficient 0.58), length of the mooring front (correlation coefficient 0.62), operational length of railway tracks (correlation coefficient 0.66), and extent of highways (correlation coefficient 0.59). Other factors have a weak impact on development of ports. In addition, for creation of multifactorial model dependence of seaports development on the considered factors was the p-test will carry out estimates of parameters of the regression equation. Based on the r-test factors the area of the territory of seaport and extent of highways since r-values more than 0.05 that testifies to insignificance of parameters of these factors were excluded.

Thus, the analysis allowed selecting two factors having a considerable impact on development of ports and satisfying to parameters of statistical assessment.

For creation of the equation of regression showing development of seaports, and we will carry out estimates of quality of the equation of regression analysis (see Table 3).

Table 3 Regression analysis of the equation of dependence of seaports development on factors of length of the mooring front and operational length of railway tracks

Regression statistics					
Plural R	0,80				
R-squared	0,64				
Standardized R-squared	0,56				
Standard error	48,07				
Observations	12				
Dispersion analyses					
	df	SS	MS	F	Value F
Regression	2	37544,47	18772,23	8,12	0,00965
Remainder	9	20803,65	2311,51		
Total	11	58348,12			
	Coeff.	Standard error	t-statistics	P-value	
Y-intersection	-48,8104	31,6056	-1,5443	0,1569	
x_4	0,0032	0,0012	2,5045	0,0336	
x_5	0,0503	0,0194	2,5818	0,0296	

Source: Own processing

Based on the regression analysis we will construct the equation of dependence of seaports development (capacity of loads transfer) on two factors:

$$Q = -48{,}8104 + 0{,}0032x_4 + 0{,}0503x_5, \quad (1)$$

Q – capacity of loads transfer, mln t;
x_1 – length of the mooring front, r.m.;
x_2 – operational length of railway tracks, km.

Function (1) adequately describes statistical data and has the high explaining ability: coefficient of correlation of r = 0.80, coefficient of determination of R^2 = 0.64, Fischer's criterion of F = 8.12. Coefficients of correlation and determination demonstrate reliability of model. The estimated F-criterion of Fischer is equal 8.12, this value is more than F-criterion tabular 3.88 that demonstrates the statistical importance of model. Assessment of parameters of the equation of regression (1) demonstrates adequacy of the selected factors since r-values x4 and x5 more than 0.05.

3.2. Econometric model of interrelation of the stevedoring industry development and regional economy

For creation of econometric model and identification of dependence of the stevedoring industry development and regional economy data of capacity of loads transfer on the Russians sea basins (mln t) and capacity of a gross regional product on regions (billion rubles) during 2005-2018 were taken. Regions are selected on presence of ports for the Russian sea basins:

- Arctic basin: Murmansk region, Arkhangelsk region, Krasnoyarsk Krai;
- Baltic basin: St. Petersburg, Kaliningrad region, Leningrad Region;
- Azov-Black sea basin: Krasnodar Krai, Rostov region, Republic of Crimea;
- Caspian basin: Astrakhan region, Republic of Dagestan;
- Far East basin: Primorsky Krai, Khabarovsk Krai, Sakhalin region, Magadan region, Kamchatka Krai.

For identification of impact of development of the stevedoring industry on development of economy of the region correlation coefficients in dynamics on each sea basins and in structure between sea basins (see Table 4) were calculated. Correlation coefficients were calculated from the capacity of cargo shipment and gross regional product for the period 2005-2018 for each basin.

Table 4 Correlation analyses of influence stevedoring industry development on regional economy based on the Russians sea basins

Indicator	Value	Characteristic
Correlation coefficient between the capacity of loads transfer and a gross regional product on the Arctic basin during 2005-2018	0,48	Correlation direct, considerable
Correlation coefficient between the capacity of loads transfer and a gross regional product on the Baltic basin during 2005-2018	0,98	Correlation direct, considerable
Correlation coefficient between the capacity of loads transfer and a gross regional product on the Azov-Black sea basin during 2005-2018	0,95	Correlation direct, considerable
Correlation coefficient between the capacity of loads transfer and a gross regional product on the Caspian basin during 2005-2018	-0,94	Correlation negatively associated, considerable
Correlation coefficient between the capacity of loads transfer and a gross regional product on the Far East basin during 2005-2018	0,99	Correlation direct, considerable
Correlation coefficient between the capacity of loads transfer and a gross regional product in a section of the sea basins of Russia for 2005	0,71	Correlation direct, considerable
Correlation coefficient between the capacity of loads transfer and a gross regional product in a section of the sea basins of Russia for 2018	0,82	Correlation direct, considerable

Source: Own processing

The correlation analysis testifies existence of interrelations between development of the stevedoring industry and regional economic development. The correlation coefficients calculated separately on each sea basin demonstrate direct significant or strong connection that demonstrates existence of strong interrelations. The exception is the Caspian basin that is connected with negative dynamics of loads transfer in this sea basin. The correlation coefficients calculated in a section of sea basin for 2005 and 2018 also demonstrate direct strong connection, at the same time for the considered period this influence only amplified (from 0.71 to 0.82).

For creation of the regression equations showing influence of capacity of loads transfer in ports on change of a gross regional product, and assessment of the equation quality of regression analysis was carried out (tab. 5 – tab. 8).

Table 5 Regression analysis the equation of dependence between a gross regional product of the Arctic sea basin and capacity of loads transfer in ports of the Arctic sea basin

Regression statistics					
Plural R	0,48				
R-squared	0,24				
Standardized R-squared	0,17				
Standard error	380,3				
Observations	13				
Dispersion analyses					
	df	SS	MS	F	Value F
Regression	1	1565406	1565406	3,38	0,09302
Remainder	11	5090894	462808		
Total	12	6656300			
	Coeff.	Standard error	t-statistics	P-value	
Y-intersection	397,41	804,1908	0,4941	0,6309	
$Q_{arct.}$	32,61	17,7296	1,8391	0,0930	

On the basis of the carried-out regression analysis we will construct the dependence equation between a gross regional product of the Arctic sea basin regions and capacity of loads transfer in ports of the Arctic sea basin:

$$GRP_{arct} = 397{,}41 + 32{,}61Q_{arct}. \quad (2)$$

Table 6 Regression analysis the equation of dependence between a gross regional product of the Baltic sea basin and capacity of loads transfer in ports of the Baltic sea basin

Regression statistics					
Plural R	0,98				
R-squared	0,96				
Standardized R-squared	0,96				
Standard error	298,9				
Observations	13				
Dispersion analyses					
	df	SS	MS	F	Value F
Regression	1	22870629	22870629	256,1	0,0000
Remainder	11	982434	89312		
Total	12	23853064			
	Coeff.	Standard error	t-statistics	P-value	
Y-intersection	-5625,73	541,7399	-10,3846	0,0000	
$Q_{baltt.}$	43,57	2,7231	16,0023	0,0000	

On the basis of the carried-out regression analysis we will construct the dependence equation between a gross regional product of the Baltic sea basin regions and capacity of loads transfer in ports of the Baltic sea basin:

$$GRP_{balt} = -5625{,}73 + 43{,}57Q_{balt} \quad (3)$$

Table 7 Regression analysis the equation of dependence between a gross regional product of the Azov-Black sea basin and capacity of loads transfer in ports of the Azov-Black sea basin

Regression statistics					
Plural R	0,95				
R-squared	0,89				
Standardized R-squared	0,88				
Standard error	374,4				
Observations	13				
Dispersion analyses					
	df	SS	MS	F	Value F
Regression	1	12953788	12953788	92,4	0,0000
Remainder	11	1541754	140159		
Total	12	14495541			
	Coeff.	Standard error	t-statistics	P-value	
Y-intersection	-2519,76	496,5557	-5,0745	0,0003	
$Q_{black\ sea}$	25,42	2,6442	9,6136	0,0000	

On the basis of the carried-out regression analysis we will construct the dependence equation between a gross regional product of the Azov-Black sea basin regions and capacity of loads transfer in ports of the Azov-Black sea basin:

$$GDP_{black\ sea} = -2519{,}76 + 25{,}42Q_{black\ sea} \quad (4)$$

Table 8 Regression analysis the equation of dependence between a gross regional product of the Far East sea basin and capacity of loads transfer in ports of the Far East sea basin

Regression statistics					
Plural R	0,99				
R-squared	0,98				
Standardized R-squared	0,98				
Standard error	100,2				
Observations	13				
Dispersion analyses					
	df	SS	MS	F	Value F
Regression	1	5932311	5932311	590,5	0,0000
Remainder	11	110512	10046		
Total	12	6042823			
	Coeff.	Standard error	t-statistics	P-value	
Y-intersection	-349,76	85,6233	-4,0848	0,0018	
$Q_{far.}$	15,79	0,6498	24,2998	0,0000	

On the basis of the carried-out regression analysis we will construct the dependence equation between a gross regional product of the Far East sea basin regions and capacity of loads transfer in ports of the Far East sea basin:

$$GDP_{far} = -349{,}76 + 15{,}79Q_{far}. \quad (5)$$

Econometric characteristics indicators equations (2)–(5) adequately describe statistical data and have the high explaining ability. Evaluation the quality of equations (1) - (4) was carried out on the basis of the results of the regression analysis carried out (Table 5 - Table 8), econometric characteristics of equations are given in Table 9.

Table 9 Econometric characteristics indicators (2)–(5)

Econometric characteristics	GRP_{arct}	GRP_{balt}	$GDP_{black\ sea}$	GDP_{far}
Correlation coefficient (*R*)	0,48	0,98	0,95	0,99
Determination coefficient (R^2)	0,24	0,96	0,89	0,98
Fisher's test (*F*)	3,4	256,1	92,4	590,5
Standard deviation (σ), billion rub.	380,3	298,8	374,4	100,2
Variation coefficient (*V*), %	20,7	10,1	17,4	6,2

Source: Own processing

The calculated econometric models for the Russians sea basins allowed to reveal the following trends:

- interrelation between the stevedoring industry development and the capacity of a gross regional product is traced both at dynamic, and at a structural research of sea basins;

- development of the stevedoring industry positively affects on economic development of regions of the sea basins;
- stevedoring industry has the greatest impact on economic development in the Baltic sea region, the smallest in Far East one.

4. PERSPECTIVES OF DEVELOPMENT AND DETERRENTS

According to Association of sea trade ports (ASTP) the power of port complexes annually grows in Russia for 3-4%. According to the FTP "Development of the transport system of Russia (2010-2020)" by 2020 the power of port complexes should will increase to 1140 million tons. According to the optimistic scenario if in the planned terms all port projects which are at different stages are implemented, then cumulative gain of transshipment capacities during the period from 2017 to 2022 can be 319 million tons that by 1.8 times exceeds the target indicator according to the FTP. According to the most probable scenario if to exclude projects, postponement probability on which is evaluated as rather high, from calculation, gain can reach 175 million tons that approximately corresponds to the FTP target indicator.

Results of survey conducted by the EY company in 2016 confirm the positive spirit of participants of the industry and their strategy aimed at the further development. Most of respondents (more than 70%) in addition to such priority strategic tasks for the medium term as updating of the worn-out equipment and improvement of quality of the rendered services, note expansion of stevedoring capacities in the existing terminals.

Among investment projects in Russian seaports it is possible to note:

- in the Arctic sea basin: development of the Murmansk transport hub, construction of the coal terminal, construction of the LNG terminal in the port of Sabetta, construction of the coal terminal in Beringovsky port, construction of the coal terminal in Dickson port;
- in the Baltic sea basin: development of transshipment facility of Bronk in the Big port of St. Petersburg, construction of transshipment oil facility in the port of Primorsk, reconstruction of the container terminal in the port of Kaliningrad, construction of the coal terminal and terminal on production and an overload of LNG in the port of Vysotsk;
- in the Azov-Black sea basin: construction of new terminals, the dry-cargo area in the port of Taman, reconstruction and expansion of capacities, construction of grain and container terminals in the port of Novorossiysk, construction of the grain terminal in the port of Azov;
- in the Far East sea Basin: construction of a coal complex in the East port, construction of coal terminals and the terminal for transfer of alumina in Vanino port, construction of the coal terminal in the port of Vera, construction of a complex on transfer of LPG in port Sovetskaya Gavan, construction of grain terminals in Zarubino port;
- in the Caspian sea Basin: the complex Development strategy of the Russian seaports in the Caspian Basin (The order of June 25, 2019 No. 1365-r) is adopted.
- Implementation of priority investment projects will allow to increase power in the Arctic sea basin on 56 million tons, in Baltic – on 25 million tons, in Azov-Black sea – on 147 million tons, in Far East – on 82 million tons, in Caspian – on 10 million tons.

Among the pacing factors constraining development of the stevedoring industry in Russia, most of experts note insufficiently fast development of railway infrastructure (69% of respondents), insufficient depth of channels in water areas of seaports (65%), growth of the competition and more favorable logistic arrangement of terminals of competitors (46%), and insufficiently fast development of automobile infrastructure (35%).

Railway transport is one of the pacing constraining factors since nearly 50% of loads arrive in ports by rail. Insufficient throughput of railway lines and access railway tracks limits for cargo owners of a possibility of export of their products and a possibility of ports in respect of increase in goods turnover.

Therefore, implementation of large-scale projects in ports is impossible without the corresponding development of railway infrastructure. Timely elimination of "bottlenecks" on the railroad is a necessary condition of successful implementation of investment projects in ports and accumulation of volumes of export from the Russian Federation.

Depth of the water area determines the maximum loading capacity of the vessel that can come into the port. At the same time, the more the vessel loading capacity, the less specific transport expenses on condition of its full load. Thus, ports that can provide run of vessels with a big deadweight with other things being equal are more attractive to cargo owners and have the bigger potential for further development, than shallow-water ports.

Saving of moderate growth rates of demand for raw material resources and the low level of the prices in the medium term can be considered as the main risk of investments into development of port capacities.

5. CONCLUSIONS

Results of this research allowed to reveal accurate localization of separate types of loads in a section of sea basins and Russian seaports generally specialize in transfer of raw material resources (coal and oil loads). Based on correlation and regression analysis influence of different factors on development of Russian seaports is investigated. The analysis allowed to select two factors having a considerable impact on development of ports and satisfying to parameters of statistical assessment: length of the mooring front and operational length of railway tracks. Based on regression analysis it is constructed econometric model of dependence of seaports development (capacity of transfer loads) on two selected factors. The model the reflecting interrelation between development of the stevedoring industry and economy of the region is constructed, the correlation analysis testifies existence of interrelations between development of the stevedoring industry and regional economic development.

Based on constructed models conclusions are drawn on existence characteristic of each analyzed port has perspectives of development and restraining factors. Among restraining factors of the stevedoring industry development in Russia are especially selected insufficiently fast development of railway infrastructure and insufficient depth of channels in water areas of seaports.

Thus, seaports play one of key roles in development of goods turnover and international trade. In seaports about 60% of the foreign trade loads of the Russian Federation are processed. The state and business realize importance of development of port infrastructure, planning a set of projects on a broad spectrum of loads. The relevant sources of financing and a measure of the state support are necessary for successful implementation of these projects.

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REFERENCES

[1] Alphainer rating: the only container port from Russian Federation — on the 84th place, [on-line]. Available on: https://news.myseldon.com/en/news/index/212907323?requestId=de16c977-3262-4ade-9e98-e7e19008c75d

[2] CARGO-REPORT.INFO, [on-line]. Available on: https://cargo-report.info/stat/

[3] Chen, H., Cullinane, K., Liu, N.: Developing a model for measuring the resilience of a port-hinterland container transportation network. Transportation Research Part E: Logistics and Transportation Review, 2017, Vol. 97, pp. 282-301. Doi: 10.1016/j.tre.2016.10.008

[4] Chen, J. Liu, A. Di, Z., Wan, Z., Tian, Y., Li, K. X., Huang, T., Zhao, M.: Evolvement of Rank-Size Distribution of Regional Container Ports: Case Study of Yangtze River Delta of China. IEEE Access, 2019, Vol. 7, pp. 61273-61282.

[5] Condition of sea transport hubs. [on-line]. Available on: https://uikc.ru/articles/sostoyanie-morskih-transportnyh-uzlov.

[6] De Langen, P.W., van der Lugt, L. M.: Institutional reforms of port authorities in the Netherlands; the establishment of port development companies. Research in Transportation Business and Management, 2017, Vol. 22, pp. 108-113. Doi: 10.1016/j.rtbm.2016.12.007

[7] Debrie, J., Raimbault, N.: The port-city relationships in two European inland ports: A geographical perspective on urban governance. Cities, 2016, Vol. 50, pp. 180-187. Doi: 10.1016/j.cities.2015.10.004

[8] Dotoli, M., Epicoco, N., Falagario, M., Cavone, G.: A Timed Petri Nets Model for Performance Evaluation of Intermodal Freight Transport Terminals. IEEE Transactions on Automation Science and Engineering, 2016, Vol. 13, No 2, pp. 842-857. Doi: 10.1109/TASE.2015.2404438

[9] Federal state statistics service, [on-line]. Available on: http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat /ru/ statistics/accounts/

[10] Halim, R. A., Kwakkel, J. H., Tavasszy, L. A.: A strategic model of port-hinterland freight distribution networks. Transportation Research Part E: Logistics and Transportation Review, 2016, Vol. 95, pp. 368-384. Doi: 10.1016/j.tre.2016.05.014

[11] Knatz, G.: How competition is driving change in port governance, strategic decision-making and government policy in the United States. Research in Transportation Business and Management, 2017, Vol. 22, pp. 67-77. Doi: 10.1016/j.rtbm.2016.08.003

[12] Lam, J. S. L.: Strategy of a Transhipment Hub: The Case of Port of Singapore. Dynamic Shipping and Port Development in the Globalized Economy, 2016, Vol. 1, pp. 12-38. Doi: 10.1057/9781137514295_2

[13] Nguyen, L. C., Notteboom, T. A.: Multi-Criteria Approach to Dry Port Location in Developing Economies with Application to Vietnam. Asian Journal of Shipping and Logistics, 2016, Vol. 32, No 1, pp. 23-32. Doi: 10.1016/j.ajsl.2016.03.003

[14] Simonova T.: Review of goods turnover of seaports of Russia. Results of 2017 // RRT-Partner [on-line]. Available on: https://www.rzd-partner.ru/wate-transport/reviews/obzor-gruzooborota-morskikh-portov-rossii-itogi-2017-goda/

[15] Song, D. W.: A road towards hub ports in the logistics era. Presentation for the Conference of Ports and Logistics. Johor Bahru. 2002.

[16] Song, L., Yang, D., Chin, A. T. H., Zhang, G., He, Z., Guan, W., Mao, B.: A game-theoretical approach for modeling competitions in a maritime supply chain. Maritime Policy and Management, 2016, Vol. 43, No 8, pp. 976-991. Doi: 10.1080/03088839.2016.1231427

[17] The industry overview of stevedoring services in Russia for 2016: analytical report. Moscow, «Ernst&Yuong». 2017. 36 c.

[18] The outcome of the seaports of Russia in 2018. [on-line]. Available on: https://sudostroenie.info/analitika/111.html (access date 07/05/2019).

[19] Turnover of the Russian seaports increased on 3,8% at 2018 (detalisation), [on-line]. Available on: http://portnews.ru/news/270776/ (access date 05.07.2019).

[20] Wilmsmeier, G., Monios, J.: Institutional structure and agency in the governance of spatial diversification of port system evolution in Latin America. Journal of Transport Geography, 2016, Vol. 51, pp. 294-307. Doi: 10.1016/j.jtrangeo.2015.02.004

[21] Zhang, W., Lam, J. S. L.: An empirical analysis of maritime cluster evolution from the port development perspective – Cases of London and Hong Kong. Transportation Research Part A: Policy and Practice, 2017, Vol.105, pp. 219-232. Doi: 10.1016/j.tra.2017.05.015

[22] Zhuang, W., Luo, M., Fu, X.: A game theory analysis of port specialization-implications to the Chinese port industry. Maritime Policy and Management, 2014, Vol. 41, No 3, pp. 268-287. Doi: 10.1080/03088839.2013.839517

PROSPECTS FOR THE DEVELOPMENT OF THE INFRASTRUCTURE OF SEAPORTS OF THE NORTHERN SEA ROUTE

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Summary

The Northern Sea Route is a part of an international transport network that provides transit transport of goods between countries in North America, Europe, and South-East Asia. The distance from Europe to Asia along the Northern Sea Route is half the length of the traditional sea route through the Suez Canal. This creates great opportunities for commercial navigation between Asia and Europe along the Northern Sea Route. Interest of various companies from Northern Europe countries (Sweden, Finland, Norway) and from China and Korea to the Northern Sea Route has increased significantly. In particular, the representatives of China and Korea plan to use the Northern Sea Route in their export-import operations and transport development. However, the increase in cargo traffic along the NSR is currently limited by the weak carrying capacity of the seaports of the Russian North. The purpose of the article is to analyze the opportunities and prospects for the development of the seaports' infrastructure of the Northern Sea Route. The study of the infrastructure development of the seaports of the Northern Sea Route was carried out using bibliographic, comparative and qualitative analysis methods. As a result of the study, it was revealed that measures to increase the safety of navigation in northern seaports and their approaches, and the construction of seaport infrastructure which is planned as a part of the national state policy of the Arctic development, will increase the import and export flows of foreign trade.

Keywords: Northern Sea Route, seaports of the Russian North, infrastructure of the seaports

1. INTRODUCTION

The transarctic shipping routes are said to provide much shorter alternatives between Europe and Asia compared to conventional routes via the Suez/Panama [17]. The Northern Sea Route (NSR) is a part of an international transarctic transport network that provides transit transport of goods between countries in North America, Europe, and South-East Asia [34]. At the same time, the distance from Europe to Asia along the Northern Sea Route is half the length of the traditional sea route through the Suez Canal. The comparison shows that the ASR will deprive the Suez and Panama Canals of their choke point roles and shorten radically the travel time between the northern Atlantic and Pacific [30, p.41].

Earlier we pointed out that "an assessment of the prospects for the development of the Northern Sea Route has showed that the cost of transportation on the lines of the Northern Sea Route even in winter with the use of a modern large-tonnage fleet is lower than the cost of bulky goods transporting by land transport modes [24]. The calculations have showed that investment costs in the development of the maritime transport infrastructure are several times lower than costs for land transport projects since the volume of transportation by block trains is increasingly limited by the capacity of the railways [32]. At the same time, the estimation of investment costs for the purchase of the fleet has showed that they do not require large government subsidies and budgetary expenses, because this task can be solved at the expense of credit sources and private investors. And the energy costs (fuel) per unit of products transportation by sea transport are also less [24].

At the present time, the Northern Sea Route is in the spotlight, as it has the most favorable ice conditions among all transarctic routes [26; 28].

Foreign and Russian companies and businessmen are seen the prospects for the development of the Transarctic routes via Northern Sea Route in the expansion of coastal shipping and in ensuring the transport component in the import and export flows of foreign trade, formed in the western and eastern regions of the world and in increasing the volume of freight transportation by foreign charterers. The results of special studies conducted in recent years among shipowners, wholesale shippers and employees of logistics companies have confirmed this conclusion [2; 15; 17; 19; 37].

Currently, the weak link of the Northern Sea Route is the Arctic ports. The current status and actual availability of ports along the entire Northern Sea Route is the main obstacle to the rapid build-up of the potential of the Northern Sea Route and the growth of freight traffic along the Transarctic Route as a whole. The main problem of ports' development on the Transarctic Path is the specialization and condition of the port infrastructure. «To date the construction and development of port facilities are extremely limited. There are no adequate docking facilities available for cargo shipped through marine transportation systems» [30, p.38]. In case of increased shipping activities in the north, an adequate port infrastructure along with facilities to repair vessels will be a major requirement of the region [30, p.39].

2. THEORETICAL AND METHODOLOGICAL BACKGROUND

Numerous studies on Arctic shipping issues have sprung up in the past two decades and they had their own exclusive aims and focuses. However, as we noted in earlier works, this list of goals and objectives is very limited and narrow in terms of researching the directions, possibilities and prospects for using the Northern Sea Route for the development of international trade and the carriage of goods [24]. Similar conclusions were made by foreign researchers who reviewed the scientific literature on the Northern Sea Route and Transarctic routes [22; 37].

However, in the last decade there has been an increase in foreign and Russian research in this area. A number of them examined transportation feasibility of the NSR, highlighting both advantages and challenges [28] and W. Østreng, K.M. Eger, B. Fløistad, A. Jørgensen-Dahl, L. Lothe, M. Mejlænder-Larsen and T. Wergeland [26]. Other foreign studies are mainly devoted to the issues of commercial arctic shipping with routes [11; 16], the analysis of the barriers to global trade in terms of shipping [30, p.35-37], the study of resources, governance, technology and infrastructure [12]. Buixadé Farré and his colleagues argued that while political interest and governance has been rapidly developing, the NSR still involves many challenges in governance, routes, infrastructure, and technology [5]. Within the framework of this problem, some researchers are studying the influence of various geopolitical factors on the development of the Northern Sea Route - for example, how the blockade of the Straits of Malacca and Singapore may affect shipping in Asia and Europe and the opening of the NSR [29].

Climate change issues in the Arctic zone are also very actively discussed under the influence of the development of economic activities (shipping and its maintenance) along the route of the Northern Sea Route. For instance, the details of the discussion on navigation feasibility can be referred to Q. Meng, Y. Zhang and M. Xu [23]. Also, these are works dedicated to expanding the possibilities of controlling the ice situation, increasing the reliability of weather forecasting in the areas where the NSR passes.

Many researchers have investigated the competitiveness of the Northern Sea Route relative to conventional shipping routes. First F. Lasserre [16] and then Q. Meng, Y. Zhang and M. Xu [23] reviewed various cost models, identified a diversity of model assumptions and cost components. A large number of works on cost competiveness of the routes were also published, including M. Liu and J. Kronbak [20], H. Schøyen and S. Bråthen [31] and all researches. Russian and foreign researchers singled out fuel and energy resources (crude oil, oil products, liquefied gas, coal), expansion of container transportations, including transit [36]; transshipment of industrial products from central regions of Russia; transshipment of products of extractive industries (ore, forest, other minerals) as promising areas for the development of the Northern Sea Route [14; 22]. Russian researchers are focused on the development of the Northern Sea Route, the organization of navigation throughout the whole year, the construction of new ports and reconstruction of existing ones, the prospects for the construction of a new icebreaker fleet, the tasks of expanding the transport accessibility of new seaports and other issues [13; 18; 38].

Finally, it is necessary to highlight the comprehensive research on the development of Transarctic routes and Northern Sea Route. First of all we should mention the comprehensive study of the Transarctic routes carried out by Adil Rashid [30]. In his dissertation, published in 2009 to the World Maritime University in partial fulfillment of the requirements for the award of the degree of master of science in Maritime affairs (Port management) "Transarctic routes: impact and opportunities for ports", many questions were formulated concerning the possibility of organizing commercial freight traffic along the Transarctic routes and answered some of them. He also formulated the need to develop the port infrastructure of TAP [30, p.37-38]. Adil Rashid singled out 5 possible routes for the transportation of goods by sea vessels on Transarctic routes [30, p.29-31] and Northern Sea Route [30, p.31-33]. The second complex work of such a plan is Ph.D. Dissertation of L. Lammers "The Possibilities of Container Shipping via the Northern Sea Route" presented in 2010 at Delft University of Technology [15].

However, among the many issues related to the development of the Northern Sea Route, one block is still little studied. These are issues related to the seaports' infrastructure development on the route of the Northern Sea Route and Transarctic routes, which allows serving ships of any type throughout the year.

The conceptual and methodological complexity of studying these issues lies in the fact that the development of Arctic ports cannot be accurately depicted with Western-based or Asian models [21]. Arctic ports are mostly specialized facilities that still retain their narrow specialization (see later Table 1in the section "Research"). Therefore, it is necessary to transform and adapt existing conceptual and methodological approaches to the conditions of the Arctic in order to create a model that is suitable for Arctic cases.

The study of the problems and prospects of the development of the Arctic port infrastructure was carried out using the methods of bibliographic and comparative analysis, structural method, qualitative analysis, and mapping. The following models are taken as the main conceptual models:

1) UNCTAD model proposed in 1992 [3];
2) WORKPORT model [3];
3) Anyport model proposed by [4].

Based on the comparative analysis method, the main elements of these models are highlighted, which can be applied to the analysis of Arctic ports.

The data sources used were the technical characteristics of the ports of the Northern Sea Route, technical reviews of the port economy of the Ministry of Fleet of the Russian Federation, reviews of international specialized agencies and international organizations.

The study of foreign sources has shown that the governments of countries having the Arctic territories in recent decades are paying more attention to the development of port infrastructure to increase transportation along the Transarctic route. The "Japanese government in collaboration with some other international organizations like GIF (Global Infrastructure Fund) are working to determine the transportation priorities to ensure the development of the required infrastructure to take full advantage of the Arctic's potential" [6]. So the legal documents of the Russian Federation were analyzed to determine the direction of state support for the development of northern ports. They are the Russia's national programs "On approval of the Regulations on the State Commission for the Development of the Arctic" [8], the Program of Socio-Economic Development of the Arctic Zone of the Russian Federation for the Period to 2020 year" [7], the Federal Target Program "Development of the Transport System of Russia (2010-2020)" [9], Arctic Strategy [1] and a number of other strategic documents.

The main focus of the study is to assess the possibilities of building a transport and logistics corridor for year-round transit transportation of cargo through the Northern Sea Route and the creation of a modern port infrastructure in the northern and Arctic regions of Russia. This task corresponds to the theoretical analysis of the project for the creation of the Arctic Container Line [10; 33]. This project is a promising direction for the development of the Northern Sea Route since the increase in container traffic has great prospects for the ocean and sea fleet and the improvement of international trade.

3. RESEARCH

The territory of the Arctic zone of the Russian Federation is 4.4 million sq. km or 26% of the total area of the Russian Federation. In this area there are currently 11 operating seaports that are capable of providing year-round transit along the Transarctic route by Northern Sea Route (see Fig.1).

Figure 1 The main sea ports of Northern Sea Route of Russia

Source: Own processing

The results of the economic activities of these ports in January-June 2019 showed an increase in their activity compared to the same period in 2018. There is also a general increase in freight traffic on this transport route.

Table 1 presents the summary results of the ports of the Arctic Basin and the Far Eastern Basin, which are part of the Northern Sea Route.

Table 1 The summary results of the ports of the Arctic Basin and the Far Eastern Basin in January-June 2019

Indicators	Arctic Basin		Far Eastern Basin	
	Cargo turnover, mln tons	Growth/ reduction,%	Cargo turnover, mln tons	Growth/ reduction,%
General indicators for Basin				
Freight turnover, total	51,7	+ 25,1%	104,9	+6,8%
transshipment of dry cargo	14,9	+5,5%	66,4	+8,6%
transshipment of bulk cargo	36,7	+35,3%	38,5	+3,9%
Indicators for individual ports				
Murmansk	30,9	+7,1%	-	-
Sabetta	13,8	+220%	-	-
Varandey	3,6	+11,5%	-	-
Arkhangelsk	1,3	-5,8%	-	-
Vanino	-	-	16,2	+9,0%
Nakhodka	-	-	13,1	+6,5%
Vladivostok	-	-	10,8	+8,8%

Source: Own processing

Table 1 shows the predominant positive trend in the development of the Northern Sea Route main ports for 6 months of 2019 and the growing importance of these ports in the transportation of goods. Forecasting the development of cargo transportation along the NSR implies a more detailed analysis of the geographical and climatic features of the NSR ports in terms of possibility of year-round navigation. It is also necessary to study the technical characteristics of the Arctic ports in terms of the ability to service vessels of various classes on the entire required list of services (fueling and drinking water, emergency medical care in full (or fast delivery to specialized hospitals), repair services, etc.). The analysis should be carried out taking into account the possibility of increasing transit container traffic.

General geographical and navigation characteristics of the most important ports of the Arctic zone of Russia are shown in Table 2.

Table 2 The geographical and navigation characteristics of the most important ports of the Arctic zone of Russia

Port name	Registration No	Location	Geographical coordinates	Navigation period
Kandalaksha	A-2	White Sea, Kandalaksha Bay	67.08°N 32.25°E	year-round
Murmansk	A-1	Barents Sea, southern knee of the Kola Bay	68.59°N 33.03°E	year-round
Arkhangelsk	A-7	White Sea, Dvina Bay, mouth of the Northern Dvina River	64.33ºN 40.31ºE	year-round
Varandey	A-4	Barents Sea, Varandey Bay Area	68.48°N 57.59°E	June 01 - December 30
Sabetta	A-18	the Kara Sea, Gulf of Ob	71.16ºN 72.04ºE	year-round
Dikson	A-16	Southeastern part of the Kara Sea, Yenisei Bay	73.30°N 80.25°E	June-October
Dudinka	A-5	Kara Sea, Yenisei River	69.24°N 86.10°E	year-round except May 21 - June 14
Khatanga	A-15	Laptev Sea, Khatanga River	70.56°N 102.28°E	June 1 - October 1
Tiksi	A-13	Laptev Sea, Buor-Khaya Bay, Tiksi Bay	71.38°N 128.53°E	July 15 – September 30
Pevek	A-10	East Siberian Sea, Chaun Bay	69.46°N 170.26°E	July 3 - October 25
Providence	A-14	Bering Sea, Providence Bay	64.26°N 173.14°E	June 01 - December 1
Egvekinot	A-11	Bering Sea, Gulf of the Cross	66.19°N 179.07°E	June 25 - November 10

Source: Own processing

In order to organize sustainable year-round cargo transportation through the NSR, it is necessary to assess in more detail the following factors affecting the actual state of the infrastructure of seaports:

- condition of port facilities (availability of moorings, storage facilities of various types, loading and unloading areas, availability of automated and intelligent port and storage management systems, etc.);
- cargo base (temporary possibilities of handling freight traffic (speed, accuracy, number of simultaneously performed work), availability of modern lifting and loading equipment, etc.);
- the composition of the cargo fleet (types and types of ships), pilotage support, as well as icebreaking support for transportation along the Northern Sea Route;
- hydrometeorological support (including the reliability of weather forecasts, estimates of ice thickness, prediction of stormy weather, etc.);
- availability of coastal and port infrastructure sufficient to support navigation and maintenance of vessels in unforeseen situations (repair docks, the range and depth of the provision of repair work, the availability of household and social infrastructure to meet the needs of ship crews, etc.);
- availability of additional transport links (river, rail, road, aviation, including small aircraft) and quantitative cargo handling capabilities;
- complexity of logistic services provided.

A list of infrastructure and technical characteristics of the most important ports of the Arctic zone of Russia is given in Table 3.

Table 3 The technical characteristics of the most important ports of the Arctic zone of Russia

Characteristics of the seaport	Kanda laksha	Murm ansk	Arkha ngelsk	Varan dey	Dikson	Dudinka	Khata nga	Tiksi	Pevek	Provi dence	Egve kinot
Port area (ha)	26	645,9	215,26	1,47	3,308	24,92	10,62	7,29	19	12,7	7,17
Port water area (km2)	5,09	53,7	1120	24,98	0,182	30,22	3,7	96 ,78	8,9	13,2	5,75
Number of berths	5	98	74	2	2	9	5	2	3	3	3
The length of the mooring front of the seaport (m)	584,5	11777,91	8794,58	199,86	149	1795, 60	400	315	500	321,4	565,32
Capacity of freight terminals in total (thousand tons per year),including	1516,8	22972,2	11532,9	12100,4	120	1885	95	67	330	345,4	350
bulk (thousand tons per year)	16,8	2500	-	12000	20	50	30	-	-	25	20
dry (thousand tons per year)	1500	18985,4	5200	80	100	1529	65	67	150	300	270
containers (thousand units in twenty foot equivalent per year)	-	123,9	5432,9	1,7	-	25,5	-	-	15	1,7	5
Maximum dimensions of ships entering the port (draft, length, width) (m)	9,8/ 200/ 30	No restric-tions	9,2/ 180/ 30	2,4/ 120/ 15	8,0/ 100/ 20	11,8/ 260,3/ 32,2	4,17 / 136 / 16,5	3,9/ 129,5/ 15,8	9/ 172,2/ 24,55	10/ 200/ 24	12/ 177/25
Area of covered warehouses (thousand m2)	11,05	91,3	134,55	1,94	3,56	-	1780	3,83	4,18	3,63	2,05
Area of open warehouses (thousand m2)	25,58	187,84	502,74	9,37	0,6	-	2500	32,35	77,8		5,3

Source: Own processing

From table 3 it can be seen that the Murmansk' seaport occupies a central place in the port system of the Northern Sea Route. Among all Russian ports of the Northern Sea Route, the Murmansk' seaport is characterized by the largest approach depths, the absence of restrictions on the passage of ships (the port is available for ships of a class from Minibulkers to Panamax), the largest number of berths, etc. Therefore, in the port of Murmansk, all types of cargo handling are performed, including containerized cargo of large volumes and heavy cargoes weighing one place up to 40 tons. Also a central base for servicing icebreakers with nuclear power units (nuclear power plant) of the FSUE "Atomflot" was created on the basis of Murmansk' seaport.

As for the other ports of the NSR, their technical characteristics currently do not meet the requirements of international container transport. The exception is the new seaports under construction (Sabetta), but they have a narrow specialization in the transshipment of fuel and energy resources and the loading of fuel tankers [.

As can be seen even from a brief description of the basic elements of Russian Arctic ports infrastructure, in case of increased shipping in the north, one of the main needs of the NSR will be the availability of adequate port infrastructure and facilities for repair and maintenance of ships. The task of improving navigation safety in seaports and their approaches and the construction of infrastructure for seaports were set to the solution of this problem within the framework of the state policy for the development of the Arctic. We already wrote about this earlier [24; 25].

An important direction in the development of the port infrastructure of the Northern Sea Route sea areas is the expansion of their specialization. Currently, some of the existing Arctic ports, as well as those under construction are primarily focused on transshipment of fuel and energy resources (crude oil, petroleum products, coal, liquefied gas) (see table 3). It is necessary to expand the capacity of these ports by creating an infrastructure for transshipment of containerized cargo, thereby exploiting the potential of all Arctic ports for the development of the Transarctic routes and Northern Sea Route.

For this, it becomes important to solve two problems.

1) It is necessary to expand existing or create new distribution terminals for servicing sea vessels, especially in cases of goods transit by trans-shipment to other modes of transport (rail, road, river). The operational processing of the increased volume of cargo will be greatly hampered without the creation of new specialized highly automated terminals [24].
2) It is necessary to deepen the forester in a number of existing ports, which would allow vessels with deeper drafts to be carried out when carrying out large-scale container shipments. This is especially actual for the ports of Arkhangelsk, Varandey, Kharasavey. A construction of a new deep-water port with an area of 180 hectares is planned with an approximate investment of 35 billion rubles to the solution of this problem within the framework of the transport strategy of the Russian Federation until 2030 [24].

4. CONCLUSION

The development of the Northern Sea Route and the Transarctic routes should ensure in the future the optimization of domestic and international freight and passenger traffic both in Russia and other countries. Also, the development of the Northern Sea Route will reduce the cost of many types of products by reducing transportation costs, which for a number of products reach 50-70% at its cost price.

The development of the Northern Sea Route will allow reducing the terms of transportation of goods. Currently, the period of products transportation from the countries of the Asian region to the European part of the continent takes 30 days or more. As part of the trial shipments of similar cargoes along the Northern Sea Route, the transportation period was 10-15 days with the fastest passage of the route in 9 days.

In order to organize sustainable year-round cargo transportation through the NSR, it is necessary to assess in more detail the following factors affecting the actual state of the infrastructure of seaports: 1) condition of port facilities; 2) cargo base; 3) the composition of the cargo fleet; 4) hydrometeorological support; 5) availability of coastal and port infrastructure sufficient to support navigation and maintenance of vessels in unforeseen situations; 6) availability of additional transport links; 7) complexity of logistic services provided.

The main measures for the modernization and integrated development of the port infrastructure should be implemented in these areas.

REFERENCES

[1] Arctic Strategy. The development strategy of the Arctic zone of the Russian Federation translated from Russian, approved by Russian President Vladimir Putin 20.02.2013, 2013, [on-line]. Available on: http: //www.research.kobeu.ac.jp/gsics-pcrc/sympo/20160728/documents/Keynote/Russian%20Arctic%20strategy%20 2013.pdf

[2] Benedyk, I. V., Peeta, S.: A binary probit model to analyze shipper and forwarding company perspectives for container shipping on the Northern Sea Route, Transportation Research Board 95th Annual Meeting. Washington D.C. 2016.

[3] Beresford, A. K. C., Gardner, B. M., Pettit, S. J., Naniopoulos, A., & Wooldridge, C. F.: The UNCTAD and WORKPORT models of port development: Evolution or revolution? Maritime Policy & Management, 2004, Vol. 31, No 2, pp. 93–107.

[4] Bird, J.: Seaports and seaport terminals. London: Hutchinson University Library, 1980.

[5] Buixadé Farré, A., Stephenson, S. R., Chen, L., Czub, M., Dai, Y., Demchev, D., Efimov, Y., Graczyk, P., Grythe, H., Keil, K.: Commercial Arctic shipping through the Northeast Passage: routes, resources, governance, technology, and infrastructure. Polar Geography, 2014, Vol. 37, No 4, pp. 298–324.

[6] Christopher, J., Fast, E.: The Arctic: Transportation, infrastructure and communications. Ottawa: Parliamentary Information and Research Service, PRB 08098E, 2008. [on-line]. Available on: www.parl.gc.ca/Content/LOP/research publications/prb0808-e.htm

[7] Decree of the Government of the Russian Federation No. 21 April 2014 366 "On approval of the state program for the socio-economic development of the Arctic zone of the Russian Federation for the period until 2020", [on-line]. Available on: http://government.ru/docs/all/91474/

[8] Decree of the Government of the Russian Federation No. 228 of March 14, 2015 "On approval of the Regulations on the State Commission for the Development of the Arctic", [on-line]. Available on: http://government.ru/docs/all/95235/.

[9] Decree of the Government of the Russian Federation No. 848 of 05.12.2001 "On the Federal Target Program Development of the Transport System of Russia (2010-2020)", [on-line]. Available on: http:/ /base.garant.ru/1587083/1

[10] Dellink, R., Chateau, J., Lanzi, E., Magné, B.: Long-term economic growth projections in the Shared Socioeconomic Pathways. Global Environmental Change, 2017, Vol. 42, pp. 200-214. DOI: 10.1016/j.gloenvcha.2015.06.004

[11] Druzhinin A.: The sea factor in the spatial and socio-economic dynamics of today's Russia. Quaestiones Geographicae, 2019, Vol. 38, No 2, Bogucki Wydawnictwo Naukowe, Poznań, pp. 91–100.

[12] Gritsenko, D., Efimova, E.: Policy environment analysis for Arctic seaport development: the case of Sabetta (Russia). Polar Geography, 2017, Vol. 40, No 3, pp. 186-207. DOI: 10.1080/1088937X.2017.1328466

[13] Ivanov, Yu. M., Romanenko, A. A, Lebedev, G.V.: Sea ports of Russia - the development trajectory. Transport of the Russian Federation, 2013, Vol. 5, No 48, pp. 8-12.

[14] Khon, V. C., Mokhov, I. I., Latif, M., Semenov, V. A., Park, W.: Perspectives of Northern Sea Route and Northwest Passage in the twenty-first century. Climatic Change, 2010, Vol. 100, No 3, pp. 757-768. DOI: 10.1007/s10584-009-9683-2.

[15] Lammers, L.: The Possibilities of Container Transit Shipping via the Northern Sea Route (Ph.D. Dissertation). Delft University of Technology. 2010.

[16] Lasserre, F.: Case studies of shipping along Arctic routes. Analysis and profitability perspectives for the container sector. Transportation Research Part A: Policy and Practice, 2014, Vol. 66, No 1, pp. 144-161. DOI: 10.1016/j.tra.2014.05.005

[17] Lasserre, F., Pelletier, S.: "Polar Super Seaways? Maritime Transport in the Arctic: An Analysis of Shipowners' Intentions". Journal of Transport Geography, 2011, Vol. 19, No (6), pp. 1465–1473. DOI:10.1016/j.jtrangeo.2011.08.006.

[18] Lebedev, G.: Modernization of the infrastructure of the Arctic marine transport system. Marine Collection, 2013, Vol. 10, pp. 40-45.

[19] Lee, S.-W., Song, J.-M.: Economic possibilities of shipping though Northern Sea Route. Asian J. Shipp. Logist., 2014, Vol. 30, No 3, pp. 415–430.

[20] Liu, M., Kronbak, J.: The Potential Economic Viability of Using the Northern Sea Route (NSR) as an Alternative Route between Asia and Europe. Journal of Transport Geography, 2010, Vol. 18, No 3, pp. 434–444.

[21] Malchow, M. B.: An Analysis of port selection. Berkeley: UMI Dissertation Services. 2001.

[22] Melia, N., Haines, K., Hawkins, E.: Sea ice decline and 21st century trans-Arctic shipping routes. Geophysical Research Letters, 2016, Vol. 43, No 18, pp. 9720-9728. DOI: 10.1002/2016GL069315.

[23] Meng, Q., Zhang, Y., Xu, M.: Viability of transarctic shipping routes: a literature review from the navigational and commercial perspectives. Maritime Policy Management, 2017, Vol. 44, No 1, pp. 16–41.

[24] Mingaleva, A.: Improving transport connectivity of regions as the basis for economic growth. Conference Proceedings – Recent Advances in Information, Tourism, Economics, Management and Agriculture -ITEMA 2017, Budapest, Hungary, October 26, 2017. pp. 358-367. ISBN 9788680194080.

[25] Mingaleva, A., Shorohova, I.: Promising directions for the creation of transport and logistics infrastructure in coastal regions. Analysis of the state and development trends of the coastal regions of Russia. Collection of scientific papers. Kazan, Buk Publishing House, 2017, Issue 2, pp. 164-169.

[26] Østreng, W., Eger, K. M., Fløistad, B., Jørgensen-Dahl, A., Lothe, L., Mejlænder-Larsen, M., Wergeland, T.: Shipping in Arctic Waters: A Comparison of the Northeast, Northwest and Trans Polar Passages. Springer Science & Business Media. 2013.

[27] Pettit, S. J., Beresford, A. K.: CPort development: From gateways to logistics hubs. Maritime Policy & Management, 2009, Vol. 36, No 3, pp. 253–267.

[28] Protection of the Arctic Marine Environment (PAME) Working Group, the Arctic Council, 2009

[29] Qu, X., Meng, Q.: The economic importance of the straits of malacca and Singapore: an extreme-scenario analysis. Transp. Res. Part E, 2012, Vol. 48, No 1, pp. 258–265.

[30] Rashid, A. Transarctic routes: impact and opportunities for ports". World Maritime University Dissertations. 2009, No 153. 81 p.

[31] Schøyen, H., Bråthen, S.: The Northern Sea Route versus the Suez Canal: Cases from Bulk Shipping. Journal of Transport Geography, 2011, Vol. 19, No 4, pp. 977–983. DOI:10.1016/j.jtrangeo.2011.03.003.

[32] Selin, V., Larichkin, F., & Novoseltceva, V.: Economic development of the Russian Arctic space by upgrading transport and logistics sector. Archives of Transport, 2014, Vol. 31.

[33] Shelomentsev, A. G., Kozlova, O. A., Mingaleva, Z. A., Bedrina, Y. B., Terentyeva, T. V. Comparative analysis of regional development of Northern Territories. Asian Social Science, 2015, Vol. 11, No 14, pp. 349-356. DOI: 10.5539/ass.v11n14p349.

[34] Sintsov A. G.: North in the system of geopolitical coordinates of modern Russia. Moscow: Gorodets, 2004. 207 p.

[35] Stopford, M. Maritime Economics. London: Routledge, Taylor and Francis Group. 1997.

[36] Verny, J., Grigentin, C.: Container shipping on the Northern Sea Route. International Journal of Production Economics, 2009, Vol. 122, No 1, pp. 107-117. DOI: 10.1016/j.ijpe.2009.03.018[15]

[37] Wang, H., Zhang, Y., Meng, Q.: How will the opening of the Northern Sea Route influence the Suez Canal Route? An empirical analysis with discrete choice models. Transportation Research Part A: Policy and Practice 2018, Vol. 107, pp. 75-89.

[38] Year-round navigation along the routes of the Northern Sea Route - tasks and solutions. Vestnik SKF, 2015, Vol.4, pp.6-7.

INFLUENCE OF FLOODING BOAT DECK COMPARTMENT ON THE SHIP'S SAFETY

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Summary

At any time whether on combat or non-combat, naval ships are susceptible to damage. During combat, navy ships are susceptible to suffer damage to a particular degree on its armament, hull or even its technical equipment. The damages are of specific nature and occur at specific places of the ship. For example, during combat, a navy ship can suffer damage from torpedoes and mine explosion, impact resulting from artillery shells, missiles or airborne bombs or even due to effects from weapons of mass destruction. This damage results in flooding of the affected areas. During the ship's operation at sea a significant threat to his safety is a fire. Rarely causes sinking of the ship, however, the damage that it leaves is usually very serious and as always, depending on the level of crew training in the area of emergency response. The main extinguishing agent used on ships is usually sea water, which in large quantities poses a threat to the safety of the ship. It affects changes in stability and position of the ship. Determination of these changes is the basis for the sub-capacity calculations related to the operation of a damaged ship. Therefore, the main focus of the work was to determine the impact of flooding of high-located compartments on the safety of a ship. The results of the calculations presented in the paper include information about the amount of water in the range causing deterioration of the stability of the ship.

Keywords: free surface effect, metacentric height, righting lever

1. INTRODUCTION

Any occurrence of a ship accident is a nightmare to many sea crews and seafarers. Marine accident affects not only human but also the properties and activities onboard the ship, functionality of ashore as well as the marine environment. These accidents are not only limited to cargo, fishing, and cruise ships, but also to the navy ships. Over the past decades, various navy ships have experienced various accidents some of which are minor while others are fatal. Some of these accidents have led to some navy ships sinking while others have been grounded for many years before being reintroduced or replaced with new ones.

As Ship is a compound technical system operated intensively in particular during military activities. Her combat abilities depend, first of all, on munitions with which the vessel is equipped and on the remaining technical measures ensuring her way [5]. Damages caused to those measures result in deterioration of the boat military capabilities and they may be followed by various reasons. Events causing damages to the ship, as to a technical system, are presented in Figure 1. Fire presents serious hazard to a ship when at sea. It results in her sinking rarely, however the left devastation is usually very serious and, as ever, depending on the level of the crew training in respect to the damage control plan. During peaceful operation of the combat vessel, short-circuits in electrical installations, failures of devices and mechanisms, self ignition of pure oxygen when contacted with petroleum materials and so on make most sources of fires. Seawater is usually the main extinguishing agent used on ships and high volumes of the water are hazardous to the vessel stability and subdivision. Therefore, in the paper, the main emphasis has been made on defining the impact of high located and flooded compartments on the ship stability safety. Results of calculations presented in the elaboration contain information regarding volumes of water in the compartment causing deterioration of the ship stability.

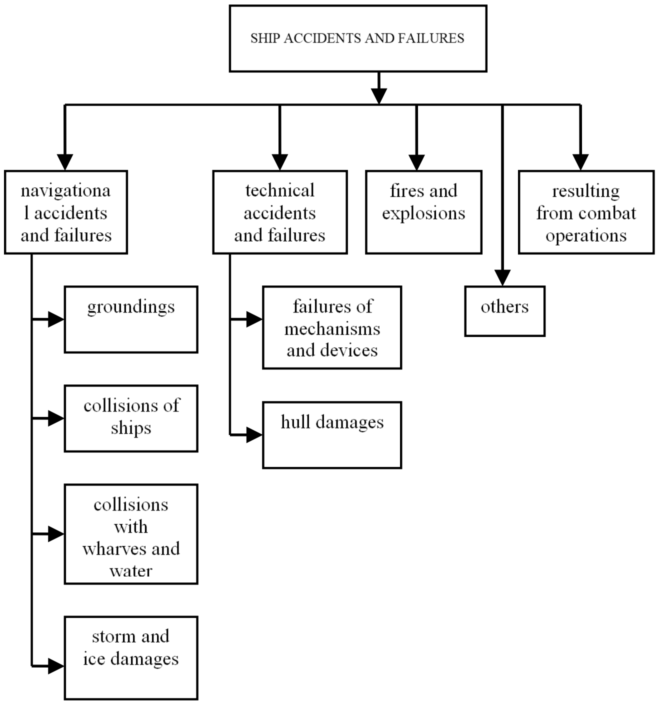


Figure 1 Break-down of ship accidents and failures

Source: [4,6]

2. CHARACTERISTICS OF RESEARCH OBJECT

The training vessel selected for the tests is a flagship of the training and research ships of our fleet. The said boat is divided, with ten transverse watertight bulkheads, into 11 watertight compartments located on the frames: 3, 16, 25, 35, 50, 60, 71, 80, 91 and 101. Such division ensures maintenance of unsinkability when two neighbouring compartments have been flooded, excluding main engine room and adjoining compartment. Analysis of the damage stability after flooding high located compartments has been justified because the ship sails in different sea waters, so in various and dangerous weather conditions where the risk of damages is high. General characteristics of the vessel - main dimensions:

overall length:	Lc = 72,20 m,
length between perpendiculars:	LBP = 64,20 m,
maximal breath:	Bmax = 12,00 m,
breath:	B = 11,60 m,
height:	H = 25,55 m.

The calculations have been made for load displacement and no icing.

Figure 2 Picture of the training vessel

Source: own study

These conditions are characterized by the following quantities:

- displacement: D = 1745,34 t,
- ordinate of the mass centre from the main plane: z_G = 4,31 m,
- stern draft: T_R = 3,97 m,
- bow draft : T_D = 4,05 m,
- average draft: $T_{śr}$ = 4,01 m,
- trim: t = 0,08 m,
- metacentr height from the main plane: z_M = 5,44 m,
- metacentric height: GM = 1,13 m,
- speed: V =16,8 kn,
- coordinates of the mass centre:

  x_G = 29,649 m from the after perpendicular,
  y_G = -0,007 m from the plane of symmetry,
  z_G = 4,314 m from the main plane [9].

3. DEFINING THE METACENTRIC HEIGHT AND THE RIGHTING LEVERS OF THE SHIP

Water broken into the vessel's hull and the flooded compartment or tank result in deeper draught of the ship, possible heel and trim as well as a change in her stability. The change may improve or aggravate operational conditions of the boat. In some case, lower stability may be serious enough to endanger safety of the ship and her crew as well as it may cause overturning of the vessel. To avoid accidents of such a kind, it is necessary to check stability of the damaged ship and apply appropriate remedial measures that would stop its lessening.

Flooding of high situated compartment or several compartments always results in aggravation of the vessel's stability. As a consequence, a heel or trim of the ship, change in the metacentric height and the righting levers may occur.

A vessel of standard displacement D for which a mass m is loaded in the point A (X, Y, Z) as in the Figure 3 [2,3,5] has been taken into consideration in the stability calculations. The training vessel selected for the tests is a flagship of the training and research ships' wing of our fleet.

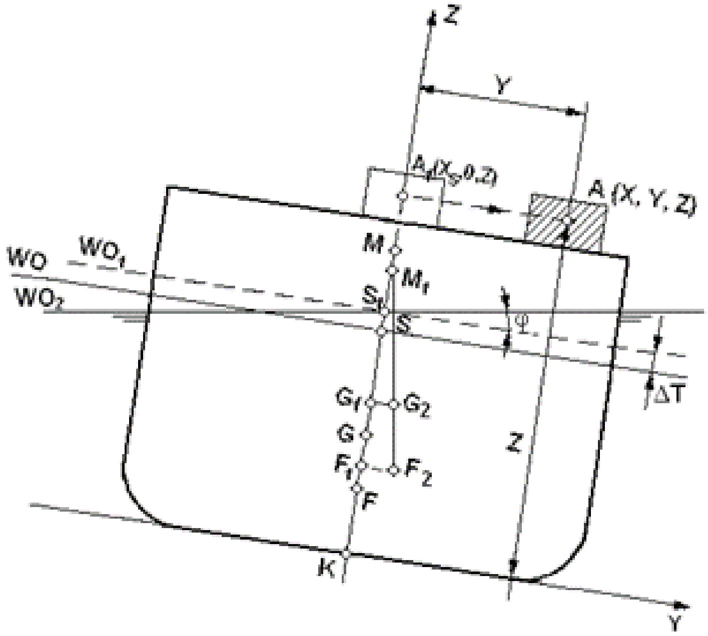


Figure 3 Scheme of the ship situation after acceptance of the mass m in the point A

Source: [2,3,5]

At the beginning, acceptance of the mass was assumed so that to have its centre vertically above the centre of water-plane section's surface WO in the point A1 (Xs, 0, Z). Then, it is possible to calculate [1,2,3]:

- the draught increase, as per the formula:

$$\Delta T = \frac{m}{\rho F_{WO}} \tag{1}$$

- the new transverse metacentric height, as per the formula:

$$\overline{G_1 M_1} = \overline{GM} + \frac{m}{D+m}\left(T + \frac{\Delta T}{2} - Z - \overline{GM}\right) \tag{2}$$

- the new longitudinal metacentric height, as per the formula:

$$\overline{G_1 M_{L1}} = \frac{m}{D+m}\overline{GM_L} \tag{3}$$

In the next step, the mass was moved from the imaginary position onto the place occupied in reality:

- towards the transverse direction by a distance of $e = Y - Y_1 = Y - 0 = Y$,
- towards the longitudinal direction by a distance of $l = X - X_S$.

The angle of heel of the ship has been calculated with the formula below:

$$tg\varphi = \frac{mY}{(D+m)\overline{G_1 M_1}} \tag{4}$$

and the trim of the vessel from:

$$tg\Psi = \frac{m(X - X_S)}{D\overline{GM_L}} \tag{5}$$

The new draughts of the bow and stern are defined from the following equations:

$$T_{d1} = T_d + \Delta T + \Delta T_d \tag{6}$$

$$T_{r1} = T_r + \Delta T + \Delta T_r \tag{7}$$

The final results are as follows:

$$T_{d1} = T_d + \frac{m}{\rho F_{WO}} + \left(\frac{L}{2} - X_S\right)\frac{m(X - X_S)}{D\overline{GM}_L} \tag{8}$$

$$T_{r1} = T_r + \frac{m}{\rho F_{WO}} + \left(-\frac{L}{2} - X_S\right)\frac{m(X - X_S)}{D\overline{GM}_L} \tag{9}$$

For large angles of heel (above 7°), the ship stability is defined based on the righting lever curves (Reed's curve). This curve allows determining dimensions of the righting lever for any angle of heel of the given ship, at invariable displacement and position of the mass centre.

Value of the righting lever is determined with the following formula applied [5]:

$$\overline{GH} = \overline{KC} - \overline{KL} \tag{10}$$

where:

$$\overline{KL} = Z_g \sin\varphi \tag{11}$$

Z_g – the mass centre height [m],

$\overline{KL}$ – the weight stability lever [m],

$\overline{KC}$ – the form stability lever [m].

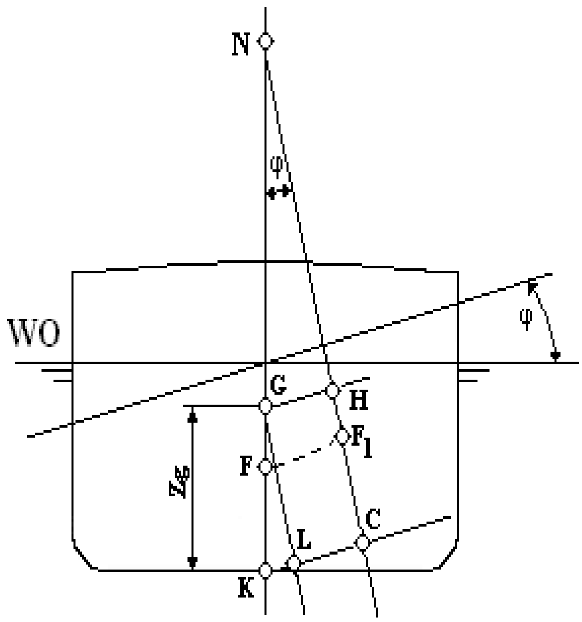


Figure 4 Righting lever of the shape and mass

Source: [5]

The formula (10) may be presented in the following way:

$$\overline{GH} = \overline{KC} - Z_g \sin\varphi \tag{12}$$

For the determination of the righting lever for any angle of heel it is necessary to know the form stability lever that changes depending on the angle of heel. This value is read from the so-called Pantecaren graph, which is developed during the design phase of the ship.

Reed's curve which is a graph of righting levers provides information about the basic parameters of the stability of the ship, such as:

φ_{Gzmax} - heeling angle at the maximum value of the righting lever occurs [deg],

GZ_{max} - the maximum righting lever [m],

φ_r - the angle of vanishing stability [deg],

GM - the metacentric height [m].

4. FREE SURFACE EFFECT

Presence of fluid free surface effect after partial flooding of compartment always results in reduction of the vessel's metacentric height. This decrease depends, among the others, on the shape and magnitude of this surface.

Receipt of liquid cargo on board of a ship, accompanied by occurrence of the free surface, has influence on change of position of the vessel mass centre and thus on the metacentric height and righting lever. Hence usage of, for instance, larger quantities of water for fire-fighting purposes on upper decks results in shifting the boat's mass centre up, and – if connected with occurrence of free surfaces – it may cause the loss of stability and overturning of the ship.

Impact of inertia moment derived from the free surface of the flooded compartment has been taken into account in the calculations of the metacentric height. It has been assumed that surface of the compartment under flooding is rectangular. The moments of inertia of the permanent constructional elements present in the compartment have been taken into consideration in calculations regarding the inertia moment of the entire body.

Determining the influence of the free surface effect of the liquid on the ship's stability the ship has been tilted by an angle φ. The layout of the partially filled liquid tank with a specific density ρ_1 and volume v is shown in Figure 5. The liquid mass in the tank is calculated [1,2,3,10]:

$$m = \rho_1 * v \tag{13}$$

At any angle of heel the liquid in the tank is poured overboard and its surface is parallel to the sea water, assuming the position of WO_1. The center of liquid mass, which in the upright position of the ship was at the point g, will move to the point g_1 as a result of the change in shape of the fluid filled volume. The shape of the tank in the transverse section of the ship resembles a cuboid. The center of fluid mass g moves over the circle with the center at the point n. So the distance can be expressed by an equation [1,2,3,9]:

$$\overline{gn} = \frac{i_b}{v} \tag{14}$$

where:

i_b – interia moment of a free surface effect [m^4],

v – volume of the liquid inside the tank [m^3].

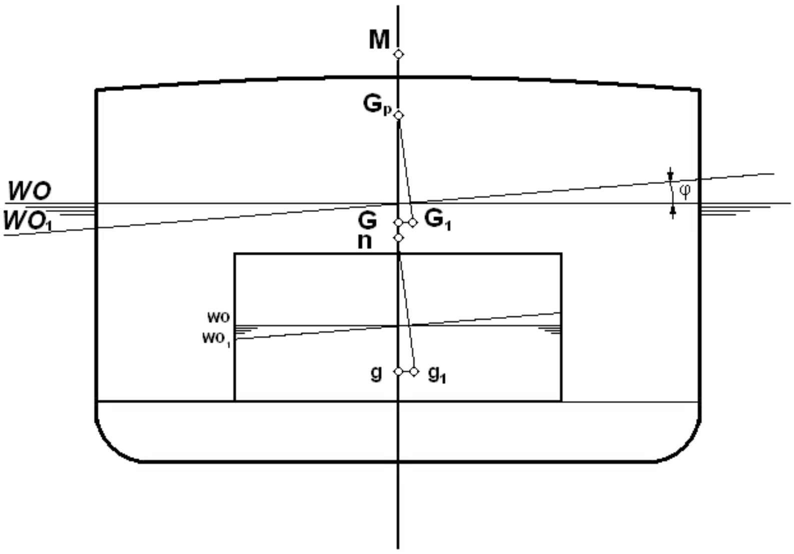


Figure 5 Ship with free surface

Source: [5]

Because at low heel angles the direction of gravity of the liquid passes through the point n, so that the influence free surface effect of the liquid in the tank on the metacentric height of the ship will be identical to the effect that would induce the shift of the constant mass (equal to the weight of the liquid), whose center of gravity has gone from point g to point n. Actual movement the center mass of the fluid will cause a parallel displacement of the center of mass of the ship from point G to point G_1, resulting in a reduction of the righting lever and thus a reduction in a ship stability. The direction of gravity force in the tilt will thus pass through G_1, crossing the symmetry plane of the ship at point Gp. For small angles of heel, the Gp point is constant. The reduction of the metacentric height due to the movement of the center mass of the ship from point G to point G_1 will be the same as the shift of center mass to point Gp. For this reason, this point is called the apparent medium of mass. The apparent displacement of the center mass of a ship from G to Gp is caused by the apparent center of mass displacement from g to point n. Therefore, the distance is calculated by the formula [1,2,3,11]

$$\overline{GG_p} = \frac{\rho_1 * v}{\rho * V} * \overline{gn} = \frac{\rho_1 * v}{\rho * V} * \frac{i_b}{v} = \frac{\frac{\rho_1}{\rho} * i_b}{V} \tag{15}$$

where:

ρ_1 - density of the water inside the tank,

ρ - density of the sea water,

V - volume of ship displacement.

Since the arbitrary movement of the liquid mass is always vertically directed and directed upwards, it is accompanied by a decrease in the metacentric height [1,2,3]:

$$\overline{G_p M} = \overline{GM} - \overline{GG_p} = \overline{GM} - \frac{\frac{\rho_1}{\rho} * i_b}{V} \tag{16}$$

where:

$\overline{G_p M}$ – reduced matacentric height

With bigger number of tanks not completely filled with liquids of different densities, the effect of free surfaces is summed up according to the formula:

$$\overline{G_p M} = \overline{GM} - \frac{\sum_{k=1}^{n} \frac{\rho_{pk}}{\rho} i_{bk}}{V} \tag{17}$$

where:

i_{bk} – subsequent interia moments of a free surface effect [m^4].

As can be seen from the above formulas, the presence of a free surface reduces the metacentric height of the ship, the reduction being dependent on the moments of inertia of the free surfaces.

Influence of the fluid free surface on the righting levers' curve (the Reed's curve) has been taken into account by implementing an allowance marked with an X symbol [1,2,3].

$$X = [y_{G1}(\varphi)\cos\varphi + z_{G1}(\varphi)\sin\varphi] \tag{18}$$

where:

$y_{G1}(\varphi)$ and $Z_{G1}(\varphi)$ - constituents of shift of the vessel's mass centre, at the heel to the angle φ[m],

$$y_{G1}(\varphi) = \frac{\sum_{i=1}^{n} m_i [y_g(\varphi)]_i}{D} \tag{19}$$

$$z_{G1}(\varphi) = \frac{\sum_{i=1}^{n} m_i [z_g(\varphi)]_i}{D} \tag{20}$$

D – ship displacement together with liquid cargo [t],

m_i –mass of the liquid cargos in particular tanks [t],

$[y_g(\varphi)]_i$ and $[z_g(\varphi)]_i$ – constituents of shifts of the fluid mass centres in the flooded compartments at the heel to the angle φ [m] [10]. These parameters have been calculated with a used of an elaborated computer programme. This software is adapted to calculate stability parameters for a floating structure of rectangular shape.

After defining the allowance from the fluid free surface, the new GM is:

$$GM = G_1 M_1 - X \tag{21}$$

Based on the formula 21, the calculations and analyses of the vessel's metacentric height after flooding the ship compartment have been made.

5. RESULTS OF THE VESSEL STABILITY WITH A FLOODED SHIP COMPARTMENT

The calculations have been made for a compartment located at the height of 8,10 m from the base plane. This compartment, of the dimensions: width 8,64 m and length 19,49 m, is represented by a plane surface, after considering its equipment, equal 147,6 m2. It was undergone flooding up to the water height H previously assumed.

The results of the righting levers calculations, with the free surface effect, for the considered water heights in the compartment, was taken into consideration. A course of changes of the righting levers' curve (the Reed's curve) versus the heel angle of the ship is presented in the Figure 6. The angles of steady heel of the ship, resulting from flooding of the vessel compartment under discussion, amount respectively: φ_{S1} = 12° for the water level in the compartment equal H = 1,0 m and φ_{S2} = 18° for H = 1,6 m. The metacentric heights for these cases display negative values.

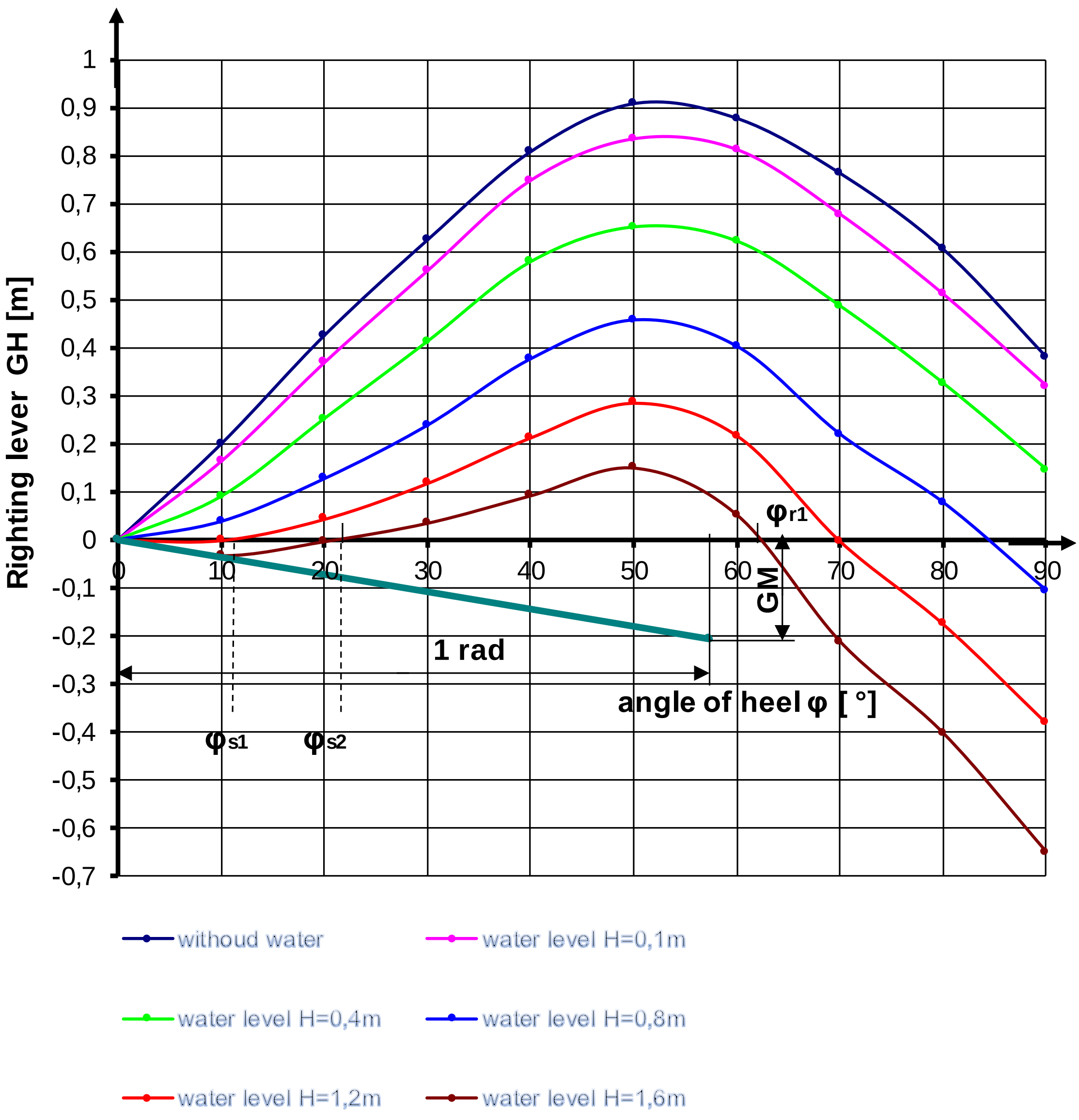
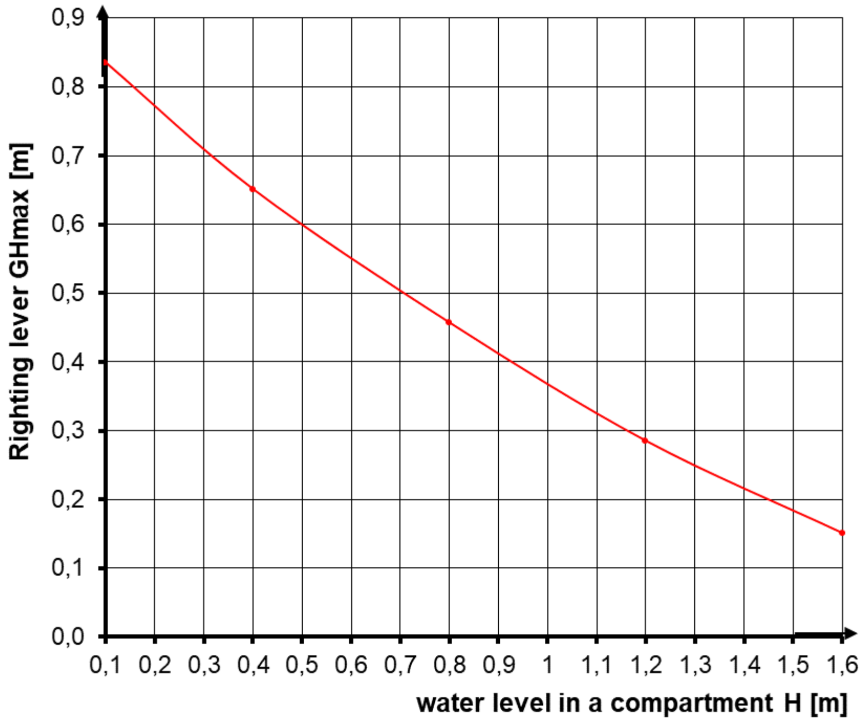


Figure 6 Influence of the amount of water in the compartment on the righting levers

Source: own study

For the amount of water in the compartment to the level H = 1.6 m the angle vanishing stability is reduced from approx. φ_r = 100 deg. for the compartment without water to approx. φ_r = 62 deg. with the water.

The graph of maximum values of righting levers changes is shown in the Figure 7.



Source: own study

Figure 7 Influence of the amount of water in the compartment on the Reed's curve

Analysis of Figure 7 shows clear variety values of the maximum righting levers depending on the water level in the flooded compartment. The values of righting levers show a decreasing tendency for an increasing water level in the compartment from GH = 0.82 m for water level H = 0.1m to GH = 0.15 m for water level H = 1.6m. Based on the worked up graph, it is possible to read the permissible value of the water level in the flooded compartment, which will reduce the righting lever to the minimum value required by the IMO (International Maritime Organization), i.e. to GH = 0.2 m. For the studied case, the water level in the range should not be greater than H = 1,45 m. A larger amount of water in the compartment may lead to the loss of stability of the ship and in a special situation it may even lead to the sinking of the ship.

7. CONCLUSION

As a result of analysis of the ship's stability after flooding a high situated compartment provides the following conclusions:

Flooding of high located compartment results in:

- a reduction in a value of metacentric height,
- a reduction in a value of righting levers,
- a reduction in the angle range righting lever φ_r,
- an increase in a value of steady heel angle φ_S.

The analysis of changes in the stability of the ship shows, that the worst option is the simultaneous flooding of two compartments have to height H = 1.2 m. It causes a loss of initial stability of the ship. The recovery of stability followed by an inclination of the ship equal $\varphi_s = 12$ °.

In future work, I intend to analyze the stability of the ship after flooding several high located compartments.

REFERENCES

[1] Derett D. R.: Ship stability for Masters and Mates, BH. Oxford, UK, 2003.

[2] Dudziak J.: Teoria okrętu, Wydawnictwo Morskie, Gdańsk, Poland 2006.

[3] Jacyna M.¸ Wasiak M, Lewczuk K., Michał Kłodawski M.: Simulation model of transport system of Poland as a tool for developing sustainable transport, Archives of Transport - Archiwum Transportu - No 3/2014 vol. 31 Warszawa, Poland, 2014.

[4] Jakus B., Korczewski Z., Mironiuk W., Szyszka J., Wróbel R.: Obrona przeciwawaryjna okrętu, cz.1, Gdynia, Poland, 2001.

[5] Kabaciński J.: Stateczność i niezatapialność statku, Gdańsk, Poland, 1995.

[6] Mironiuk W.: Preliminary research on stability of warship models, COPPE Brazil, Rio de Janeiro, 2006.

[7] Mironiuk, W., Pawlędzio, A., Wróbel, R. Trenażer do walki z wodą. Przegląd Morski nr 5, Gdynia, Poland, 2004.

[8] Mironiuk W., Pawlędzio A., Wróbel R.: Analiza stateczności statycznej pontonu prostopadłościennego o wymiarach LxBxH. Zeszyty naukowe AMW. Gdynia, Poland, 2004.

[9] Mironiuk W., Pawlędzio A., Zacharewicz M.: Badania modelowe stateczności i niezatapialności okrętów. AMW Gdynia, Poland, 2006.

[10] Mironiuk W., Pawlędzio A.: Modelling studies of the roll and the pitch training ship. Maritime Transport & Shiping, London, UK, 2013

[11] Przepisy klasyfikacji i budowy okrętów wojennych. Część IV, Stateczność i niezatapialność. Polski Rejestr Statków, Gdańsk, Poland, 2008.

[12] Szozda Z.: Stateczność statku morskiego. Akademia Morska, Szczecin, Poland, 2004.

[13] Więckiewicz W.: Podstawy pływalności i stateczności statków handlowych. AMG, Gdynia, Poland, 2006.

IMPACT OF MARITIME REGULATORY COMPLIANCE ON MARITIME SAFETY

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Summary

Poor safety practices and unsafe ships make seafaring one of the most dangerous of all occupations. The aim of this paper is to determine the influence of the maritime regulatory system on current safety level in maritime industry. Attention will be given to the guidelines of the ISM Code and MLC Convention. ISM Code provides shipping companies only the guidelines on which they should act in order to fulfill legal obligations and increase safety level. MLC Convention, in terms of the successful working and living conditions improvements, particularly Title 2 - Health protection, medical care and social security implementation will be verified.

Keywords: ISM Code, MLC Convention, shipowner compliance

1. INTRODUCTION

Maritime industry is commonly categorized as one of most complex and dangerous industries at the global level [1, 2]. At the same time it is also considered as a highly regulated industry with reinforced regulations, especially during the last two decades [3, 4].

In order to ensure safety of maritime operations, International Maritime Organization (IMO) introduced a whole set of international conventions and resolutions, among which International Convention for the Safety of Life at Sea (SOLAS) stands out. The main objective of the SOLAS Convention is to set minimum standards for the construction, equipment and operations of the ships, elaborated throughout 12 chapters. Following the capsizing of the ferry *Herald of the Free Enterprise* in 1987, IMO adopted International Safety Management Code for the Safe Operation of Ships and Pollution prevention (ISM Code) contained in Chapter IX of SOLAS Convention [5]. ISM Code requires that Safety Management System (SMS) must be established by the ship-owner or any person in charge of the ship and it became mandatory for passenger and for ships carrying dangerous cargoes in 1998, then for the rest of the ships in 2002 [6]. These and other regulations have led to partial safety improvements of maritime operations and in maritime organizations in general [7]. According to recent research effect of safety regulations and guidelines on actual proactive approach on safety is still questioned [8]. Furthermore, common issues regarding the design and implementation of SMS are still influenced by limited approach which focuses only on fulfilling regulations demands [9]. Requirement that SMS should represent and support development of maritime operations [10, 11] and to provide protection against human error [12, 13] has also been recognized.

Maritime Labour Convention 2006 (MLC) is generally considered to be the "fourth pillar" of the international regulatory regime for shipping, complementing the key instruments of the IMO, namely: SOLAS ; the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 (STCW); and the International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL). When implementing the MLC, 2006, in addition to the existing ILO instruments, all relevant IMO instruments, such as ISM Code, should be taken into account [14].

MLC, 2006 is explicitly intended to introduce human and social rights and protection for seafarers and it has been designed for uniform implementation. Convention covers a whole range of subject areas in order to improve living and working conditions of seafarers, eg. employment conditions, accommodation, medical care and health protection, work and rest hours and other [15].

Research conducted in 1995 dealt with the causes of major accidents in various types of organizations. According to author, the accident sequence begins with the negative consequences of organizational processes (decisions regarding planning, scheduling, forecasting, designing, determining, communicating, regulating, maintaining) and processes themselves are the product of the impacts and constraints under which the organization operates. The research indicated that the cause often lies in the management structures and concluded that it may not be possible to prevent the occurrence of organizational errors, but it is possible to provide the means to be visible before combining with local drivers to violate various obstacles, defense and safeguards [16].

Research by Oltendal and Engel explored gaps between safety regulations and operational practices and results in the maritime industry. Conclusion is that the shipping industry has a retroactive approach, i.e. it only response when accident occurs and this approach is often directed towards the person. The safety measures taken are usually aimed for controlling human activity, often in the form of excessive use of procedures and checklists. It also underlines that these measures are standardized to suit everyone, regardless of whether the fleet is five or 100 ships. In reality, all ships are different, as well as individuals and working groups, and emphasize that standardization alone cannot match reality. However, human actions and their deviations are compared to the standard and are considered to be wrong [17].

In other research 94 maritime accidents were investigated in order to find causal factors, both human and organizational. The time interval of the selected reports is aligned with the implementation of the ISM code, from July 2002 until the release of the new edition of the ISM Code in July 2010. The research has shown that the most frequent causal factor is the non-compliance with the ISM Code. Examples have shown that shipping organizations failed to provide the masters with clear instructions on responsibilities, and thus led to their bad decisions. In addition, it was found that organizations had failed to provide additional crew training, work procedures for major shipboard operations were standardized, differences between ship types were not considered, and disuse or limited use of the risk assessment system. Research conclusion was that the management structures of the analyzed organizations considered the ISM Code as a management tool, crew involvement in the development of SMS didn't exist, all resulting in a poor working environment [18].

Considering mentioned researches and maritime regulatory system in place it is to be expected that maritime industry safety level should be high. In reality that is often not the case.

2. ROLE OF PORT STATE CONTROL –STATISTICAL REVIEW

Port State Control (PSC) is an internationally agreed regime for the inspection of foreign ships in national ports, by authorized PSC inspectors. The roots of the PSC are contained in the Hague Memorandum, 1978, where it was agreed to monitor working conditions on ships. Following the maritime accidents of the vessel "Amoco Cadiz" it was decided that pre-agreed surveillance would include additional safety items as well as protection from pollution from ships. In that sense, in 1982 a Paris Memorandum of Understanding (Paris MoU) was signed establishing a monitoring of European port states on ships calling their ports. To date, nine regional agreements (MoU) on port State Control have been signed. PSC official's duty is to examine the compliance of a ship with the requirements of international conventions, such as SOLAS, MARPOL, STCW and MLC. Inspections may include checking the vessel required number of crew members, if they are managed in accordance with applicable international law and the condition of the ship and equipment. In other words, the PSC can be considered as the last line of defense which oversees the implementation of international maritime regulations. A Paris MoU and Tokyo MoU sector of jurisdiction stands out from the others since they are covering the main and busiest ports in the world. Ratio between conducted numbers of inspections and number of inspections with deficiencies found is presented in table 1.

Table 1 Ratio of conducted inspections with those found with deficiencies 2015-2017

Ship Type	Tokyo MoU			Paris MoU		
	2015	2016	2017	2015	2016	2017
Bulk Carriers	11431 / 6475	11397 / 6520	11337 / 6633	3646 / 1975	3619 / 1934	3730 / 1985
General cargo	6782 / 5380	6698 / 5158	6220 / 4660	5119 / 3171	5048 / 3243	4922 / 3180
Container	5058 / 2967	5058 / 2776	5154 / 2551	1768 / 819	1814 / 791	1833 / 810

Source: Authors as per [19, 20]

According to inspection results from Tokyo MoU it is evident that most vulnerable ship types are bulk carriers, general cargo followed by container ships where more than half inspections resulted with some sort of deficiency found. With respect to the flag the ships are flying worst situation is with Panama (19,466 deficiencies), Liberia, Marshall Islands, Hong Kong and Belize, all having above 4,000 deficiencies found. These flags are known as Flags of Convineience-FOC. Besides ships flying the FOC, worrying is the fact that the EU flag ships are also present on the infamous list, Malta-2357 deficiencies, Cyprus 1,011 and Greece with 636 deficiencies found during inspection. Results of Paris MoU are similar, only in this case most vulnerable are general cargo ships, bulk carriers followed with container ships.

One of the important items to be checked during the inspection is quality of ISM implementation. Available statistical data for period 2015 – 2017 from nine MoU's indicates that deficiencies are still present – table 2.

Table 2 ISM related deficiencies found by Port State Control during 2015-2017

	ISM related deficiencies		
	2015	2016	2017
Abuja MoU	8	4	15
Black Sea MoU	584	443	535
Caribbean MoU	51	27	14
Indian Ocean MoU	630	646	432
Latin America MoU	214	173	158
Mediterranean MoU	447	314	242
Paris MoU	1810	1839	1774
Riyadh MoU	30	28	211
Tokyo MoU	2803	2192	1987

Source: Authors as per [19-27]

At first glance, the stable decline in number of found ISM deficiencies, in observed time period, can be noticed especially in Paris and Tokyo MoU sectors of jurisdiction. Although in slight decline presented numbers are serious warning on issues regarding ISM implementation. Considering the fact that ships are limited with time alongside, PSC inspectors usually do not have enough time for more detailed inspection. Real number of present deficiencies in maritime industry can be discussed.

In addition to the above, inspections related to Merchant Shipping Convention (ILO 147) and MLC 2006 implementation and compliance also fall into the job description of the PSC inspector. Working and Living Conditions Deficiencies (ILO 147)[1] found by Port State Control during 2015-2017 are presented in table 3.

Table 3 Working and Living Conditions Deficiencies (ILO 147) found by Port State Control during 2015-2017

	PSC Working and Living Conditions Deficiencies (ILO 147)					
	Working Conditions (Code 9200)			Living Conditions (Code 9100)		
	2015	2016	2017	2015	2016	2017
Abuja MoU	34*	62*	45*	* data provided in one group category "Working and living Conditions" (code 9000)		
Black Sea MoU	1445	1132	1150	395	261	181
Caribbean MoU	173*	87*	122*	* data provided in one group category "Working and living Conditions" (code 9000)		
Indian Ocean MoU	629	639	661	128	161	143
Latin America MoU	0	201	339	368	109	95
Mediterranean MoU	2060*	1576*	1327*	* data provided in one group category "Working and living Conditions" (code 9000)		
Paris MoU	967	781	366	198	193	18
Riyadh MoU	0	0	119	0	0	47
Tokyo MoU	2866	2,501	2,288	349	403	383

Source: Authors as per [19-27]

As it can be seen compliance with ILO 147 requirements, especially with required working conditions, still present big issue for maritime industry. Unfortunately, such way of keeping records in form *working and living conditions,* i.e. recording of the deficiencies is reduced to two basic categories, is inadequate since it doesn't provide a detailed insight into the problem.

MLC 2006 requirements and related inspections provide a better and more detailed view of related issues. Working and living conditions deficiencies (MLC, 2006)[2] found by Port State Control during 2015-2017 are presented in table 4.

[1] For Member States of the MoU that have not ratified the MLC, 2006, enforcement of the Merchant Shipping Convention (ILO147) and the protocol of 1996 to the Merchant Shipping Convention (ILO P147) are applicable

[2] On 20 August 2013 the Maritime Labour Convention 2006 entered into force. Only Member States of the MoU that had ratified the MLC, 2006 on or before 20 August 2012 were entitled to conduct PSC inspections on MLC,2006 requirements from 20 August 2013

Table 4 Working and Living Conditions Deficiencies (MLC, 2006) found by Port State Control during 2015-2017

	PSC Working and Living Conditions Deficiencies (MLC, 2006)*											
	Minimum requirements for seafarers (Title 1) (code 18100)			Conditions of employment (Title 2) (code 18200)			Accommodation, recreational facilities, food and catering (Title 3) (code 18300)			Health protection, medical care, social security (Title 4) (code 18400)		
	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017
Abuja MoU	data not provided (ILO coded deficiencies applicable)											
Black Sea MoU	4	6	18	26	30	22	102	198	381	1062	1572	2176
Caribbean MoU	data not provided (ILO coded deficiencies applicable)											
Indian Ocean MoU	17	5	25	210	166	166	483	318	296	700	663	617
Latin America MoU	n/a	4	0	n/a	2	7	n/a	12	18	n/a	11	41
Mediterranean MoU	303**	428**	728**	** data provided in one group category (code 18000)								
Paris MoU	62	121	77	404	553	383	1782	2044	2103	2839	3067	3401
Riyadh MoU	0	0	0	0	0	0	5	5	0	0	0	0
Tokyo MoU	35	38	73	515	483	631	998	1,025	1,354	1699	2,172	2,504

Source: Authors as per [19-27]

From presented data in table 4 it is evident that all observed categories tend to deterioration, especially Health protection, medical care, social security - Title 4 of MLC, 2006. One of the most important determinants of Title 4 is „to *ensure that seafarers' work environment on board ships promotes occupational safety and health* "[15] and Regulation 4.3 – Health and safety protection and accident prevention can be considered as most important one. According this regulation each ship shall have effective occupational safety and health policies and programs, training should be provided and reasonable precautions to prevent occupational accidents, injuries and diseases should be adopted, implemented and promoted [14].

3. INTERNATIONAL TRANSPORTATION FEDERATION- STATISTICAL REVIEW

The International Transport Workers' Federation (ITF) is an international trade union federation of transport workers' unions. The ITF has a network of around 130 Inspectors, based in ports all over the world. ITF Inspectors are union officials, who are either full time or part time working on issues concerning the ITF Flag of Convenience (FOC) Campaign. FOC Campaign is worldwide campaign in the maritime industry against the use, by ship owners, of Flags of Convenience to escape from national laws and national unions. Their job is to inspect ships calling in their ports, to ensure the seafarers have decent pay and required working and living conditions on board. They conduct routine inspections and also visit ships on request of the crew. If necessary, they assist with actions to protect seafarers' rights as permitted by law. One of the most important items of the ITF inspectors is the power to legally board a vessel with an ITF agreement in order to carry out an inspection [28]. Total number of ITF inspections and related deficiencies for period 2015-2018 is presented in tables 5 and 6.

Table 5 Number of inspections and related problems found by ITF during 2015-2018

	Total number of ITF inspections	Number of inspections WITH problems	Number of inspections WITHOUT problems
2018	9739	7346	2393
2017	9160	6959	2201
2016	9502	7082	2420
2015	9717	6684	3033

Source: [29]

Presented data for year 2018 indicate that more than three quarters of conducted inspection resulted with some kind of deficiencies found. In previous years situation was similar and presented data laed to conclusion that unscrupulous ship owners still exist.

Table 6 Top five problems found by ITF during 2015-2018

Top five problems by type found during ITF inspections	2015	2016	2017	2018
Agreement	-	2685	2502	3049
Owed Wages	1713	1665	1490	1433
Breach of Contract	1397	1442	1410	1417
International Standards Non Compliance	831	947	778	1243
Medical	260	236	260	307

Source: [29]

Data presented in table 6 indicate that Title 2- Conditions of employment, set in MLC, 2006 are the most problematic area ITF deals with and no signs of improvement are present in the maritime industry.

4. MARINE CASUALTIES AND INCIDENTS IN EUROPEAN UNION

One of the numerous tasks of the European Maritime Safety Agency (EMSA) is to keep and maintain European Maritime Casualty Information Platform (EMCIP). As per Directive 2009/18/EC reporting obligation covers all casualties and incidents that occurred within EU member's waters, involve ships flying the EU member's flag or other substantial interests of EU.

Statistical data from 2011 – 2017 indicate that 23,264 ships was involved and 20,616 casualties and incidents were reported. From the total number of reported casualties and incidents, 603 cases were classified as very serious casualties, 6812 persons were injured and 683 cases ended with fatal consequences. Table 7 provides a detailed insight into cases for each year separately.

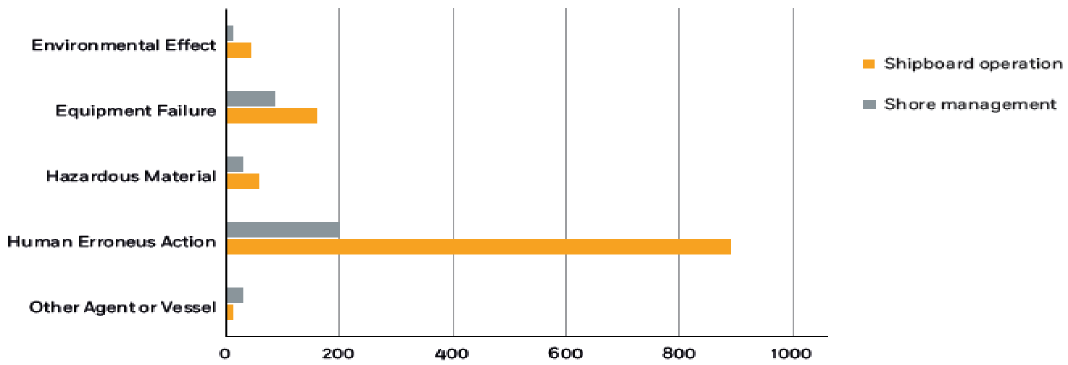
Table 7 Reported marine casualties and incidents from 2011-2017

	Casualties and incidents	Very serious casualties	Fatalities	Person injured	Ships lost	Ships involved	Investigations
2017	3301	74	61	1018	12	3647	122
2016	3145	79	106	957	26	3505	123
2015	3296	91	115	976	36	3669	125
2014	3025	99	136	1075	51	3399	125
2013	2767	81	87	933	54	3111	172
2012	2117	58	103	781	32	2432	122
2011	1271	70	67	463	41	1497	114

Source: [30]

As shown in table 7 number of reported cases of casualties and incidents has been growing steadily, same as the number of ships involved. Provided data can be interpreted in two ways, either maritime industry safety level is steadily decreasing or the shipping companies realized the importance of meeting EU requirements and began to report actual cases of accidents and incidents. Conducted investigations revealed that 57.8% of all accidental events are related to human erroneous actions out of which shipboard operations and shore management operations are stated as main contributing factor [30].

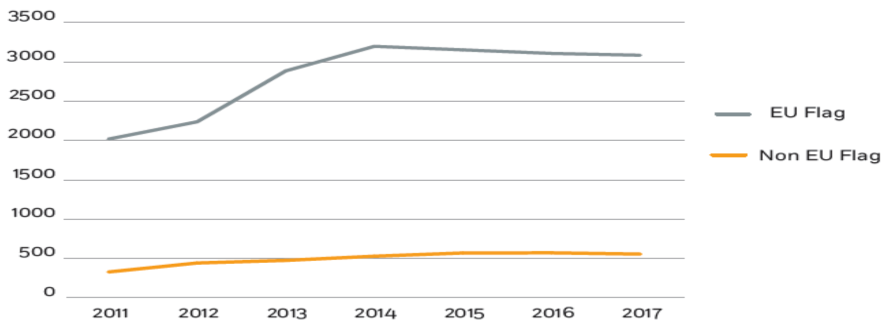
Cargo ships, in particular general cargo and container ships, are the most vulnerable category considering distribution of casualties and incidents and their occurrences per ship type. Engine room is stated as a main location of casualties onboard a cargo ships (23%), followed by over side (13.4%), cargo areas (7%), outside decks (6.6%) and forecastle deck (5.9%) [30]. Among accidental events related to cargo ships human erroneous actions (60.8%) and equipment failure (20.1%) were stated as main contributing factors – graph 1.



Graph 1 Relationship between accidental events and main contributing factor for cargo ships (2011-2017)

Source: Adopted from [30]

Considering all accidental events onboard cargo ships and data that shipboard operations are the most significant factor (76.4%) followed by shore management actions (23.6%) it is evident that ISM Code, in particular item 7 - Shipboard Operations implementation, and MLC, 2006, in particular Regulation 4.3 - Health and safety protection and accident prevention, failed in the greatest proportion. Same as in researchers mentioned above, shore management erroneous actions are still present, although in smaller ratio. Ratio of EU and non EU flagged ships involved in marine casualty and incident is presented in graph 2.



Graph 2 Distribution of ship flags involved in maritime casualty and incident accident (2011-2017)

Source: Adopted from [30]

Although the data indicate a dramatic situation on ships flying the EU flag comparing with other, non EU flag ships, it is necessary to take them with reserve as the FOC ships can understand the legal requirement for reporting accidents and incidents in a more liberal way.

5. DISCUSSION AND CONCLUSION

The presented data suggest that the compliance of shipping organizations with maritime legislation is questionable, especially in those organizations that operate general cargo, bulk and container ships. Also, it is evident that majority of these ships is sailing under flag of convenience. There is also concern that ships flying the flag of individual EU countries are among those ships that have been inspected and deficiencies were found.

In spite of all the efforts human erroneous actions are still the leading contributing factors for all reported accidental events occurred. Accidents and incidents can occur when ships are under pressures to meet unrealistic schedules with an insufficient number of crew members. Owners sometimes cut corners by not maintaining the ship and its equipment and delivery of cargoes and the costs of any delay are their only concerns.

Based on reported cases to EMCIP 1070 investigations were initiated and completed. In total, safety recommendations were sent to 1949 addresses (e.g. classification societies, owner/company, port authorities, shipyard / industry). Each recommendation is related to one or more focus areas. Operating practices may be considered as the most vulnerable area since 40% of safety recommendations refer to them. Addresses of shipping companies whose ship/s were involved in the accident were represented in 50.1% cases and in 19.6% maritime administrations. Interesting fact is that from 1420 provided answers to issued safety recommendations 52% was considered positively, either fully or partially, 7.3% was refused, while on 506 safety recommendations there was no reply by the addressee, in the largest proportion Owner/Company, followed by the Maritime Administrations [30]. These data indicate that even the EU flag ships are becoming vulnerable, in term that some shipping organizations give more importance to profit rather than safety.

Besides stated, FOC ships are another problem present in maritime industry. National regulation can be so easily undermined by any successful company with the method "one ship - one company" and branch offices in convenient countries. Ships registered under FOC have fewer regulations therefore have greater potential for unsafe practices.

Tens of thousands of seafarers endure miserable, life-threatening conditions on sub-standard vessels. Many of the detentions by Port State Control authorities involve old and badly maintained FOC vessels that should never have sailed. Many of these ships have been referred to as "floating coffins". On the other side, seafarers who are employed on FOC ships are often denied their basic human and union rights since FOC registers do not enforce minimum social standards. Despite all the efforts many seafarers sailing at FOC ships are too frightened to complain. The reason why this is not done is that unscrupulous manning agents circulate the names of seafarers complaining to ITF or PSC inspectors. Also, it's common practice for a ship's captain to write "ITF Troublemaker" in a seafarer's discharge book [29]. Standardization of working and living conditions should be the ultimate goal of all involved parties and PSC and ITF play a crucial role in achieving this.

REFERENCES

[1] Hetherington, C., Flin, R., Mearns, K., 2006. Safety in shipping: the human element. Jornal of Safety Research, 37, pp. 401–411. Available from: http://dx.doi.org/10.1016/j.jsr.2006.04.007

[2] Celik, M., 2009. Designing of integrated quality and safety management system (IQSMS) for shipping operations. Safety Science, 47, pp. 569–577. Available from: http://dx.doi.org/10.1016/j.ssci.2008.07.002.

[3] Kristiansen, S., 2008. Marine safety – Background. In: Molland, A. (Ed.), The Maritime Engineering Reference Book. Butterworth Heinemann, pp. 786–875 (Chapter 11).

[4] Chauvin, C., Lardjane, S., Morel, G., Clostermann, J.P., Langard, B., 2013. Human and organizational factors in maritime accidents: Analysis of collisions at sea using the HFACS, Accident Analysis and Prevention 59, pp. 26-37. Available from: http://dx.doi.org/10.1016/j.aap.2013.05.006

[5] SOLAS - CONSOLOIDATED EDITION 2014. Consolidated text of the International Convention for the Safety of Life at Sea, 1974, and its Protocol of 1988: articles, annexes and certificates, London, 2014.

[6] IMO - International Maritime organization. Available from: www.imo.org [Accessed 01 April 2019]

[7] Kristiansen, S., 2013. Maritime Transportation: Safety Management and Risk Analysis. Routledge.

[8] Schröder-Hinrichs, J.U., Hollnagel, E., Baldauf, M., Hofmann, S., Kataria, A. 2013. Maritime human factors and IMO policy, Maritime Policy & Management, 40:3, 243-260, DOI: 10.1080/03088839.2013.782974

[9] Schröder-Hinrichs, J.U. (2010) Human and Organizational Factors in the Maritime World – Are We Keeping up to Speed? WMU Journal of Maritime Affairs, Vol. 9, No.1, pp.1–3.

[10] Flin, R., Mearns, K., O'Connor, P., Bryden, R., 2000. Measuring safety climate: identifying the common features, Safety Science, Vol.34, pp .177-192. Available from: https://doi.org/10.1016/S0925-7535(00)00012-6

[11] Ek, A., Runefors, M., Borell, J., 2014. Relationships between safety culture aspects – A work process to enable interpretation, Marine Policy, Vol 44, pp. 179-186. Available from: http://dx. doi.org/10.1016/ j.marpol.2013.08.024

[12] Dien, Y., 1998. Safety and application of procedures, or how do 'they' have to use operating procedures in nuclear power plants, Safety Science 29, pp. 179–187.

[13] Dekker, S., 2003. Failure to adapt or adaptions that fail: contrasting models on procedures and safety, Applied Ergonomics 34, pp. 233-238

[14] Guidelines for implementing the occupational safety and health provisions of the Maritime Labour Convention, Intenational Labour Office, Geneva 2006.

[15] MLC, 2006. Maritime Labour Convention, International Labour Conference, 2006

[16] Reason, J., 1995. A systems approach to organizational error, Ergonomics, Vol.38:8, pp. 1708-1721.

[17] Oltedal, H.A., Engen, O.A., 2011. Safety management in shipping: Making sense of limited success, Safety Science Monitor, Vol. 15, pp. 1-19.

[18] Batalden, B.M., Sydnes, A.K., 2014. Maritime Safety and the ISM code: a study of investigated casualties and incidents, WMU Journal of Maritime Affairs, Vol.13, pp. 3–25.

[19] Port State Control in the Asia-Pacific Region, Annual Report 2015-2017. Available from: http://www.tokyo-mou.org [Accessed 22nd May 2019]

[20] Paris Memorandum of Understanding on Port State Control, Annual Report 2015-2017. Available from: www.parismou.org [Accessed 22nd May 2019]

[21] Riyadh Memorandum of Understanding on Port State Control, Annual Report 2015-2017. Available from: www.riyadhmou.org [Accessed 22nd May 2019]

[22] Mediterranean Memorandum of Understanding on Port State Control, Annual Report 2015-2017. Available from: http://197.230.62.214/Annual_rep.aspx [Accessed 22nd May 2019]

[23] Indian Ocean Memorandum Of Understanding on Port State Control, Annual Report 2015-2017. Available from: http://www.iomou.org/ [Accessed 22nd May 2019]

[24] Memorandum of Understanding on Port State Control for West and Central African Region- Abuja MoU, Annual report 2015-2017. Available from: http://www.abujamou.org [Accessed 22nd May 2019]

[25] Port State Control in the Black Sea Region, Annual Report 2015-2017. Available from: http://www.bsmou.org [Accessed 22nd May 2019]

[26] Port State Control Caribbean MoU, Annual Report 2015-2017. Available from: http://www.caribbeanmou.org/ [Accessed 22nd May 2019]

[27] Latin America Mou, DocumentoPresentadoPorSecretaría Del AcuerdoViña Del Mar, Annual Report 2015-2017. Available from: http://alvm.prefecturanaval.gob.ar [Accessed 22nd May 2019]

[28] ITF Seafarers. Available from: https://www.itfseafarers.org/what-inspector-can-cant-do.cfm) [Accessed 01st June 2019]

[29] International Transport Workers Federation . Available from: https://www.itfglobal.org [Accessed 01st June 2019]

[30] Annual Overview Of Marine Casualties And Incidents 2018, European Maritime Safety Agency. Available from: http://emsa.europa.eu/publications/technical-reports-studies-and-plans/item/3406-annual-overview-of-marine-casualties-and-incidents-2018.html. [Accessed 20 May 2019]

INTRODUCING ELECTRIC SHIPS IN THE COASTAL MARITIME TRAFFIC SYSTEM OF THE REPUBLIC OF CROATIA

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Summary

Croatia is a maritime country with an extremely indented coastline. According to the last population census in 2011, 2.92% of the total population in Croatia live on the islands, so the coastal maritime transport is one of the most important factor for the life of its population and sustainable development of the islands. Maritime transport is an initiator for economic and social development, but like all other types of traffic, it has adverse impacts on the environment and quality of life, because it causes various types of pollution and changes in living space. To reduce the negative impacts of maritime transport on the environment, alternative solutions of engine fuels with lower emission of harmful gases are present more and some changes can be expected in the coastal maritime transport of the Republic of Croatia. The aim of this paper is to examine the possibility of introducing electric ships in the present system. Analyzing attitudes shipping companies and employees in the public sector system, it can be concluded that there is awareness of the impact of maritime traffic on the environment and pollution, but it requires a significant investment in infrastructure. From such knowledge comes the need for a systematic and scientifically based research to create the most important preconditions for greater use of environmentally acceptable fuels and in that way limit the negative impact of maritime transport on the environment.

Keywords: coastal maritime traffic in Croatia, impact of maritime transport on the environment, alternative fuels in maritime transport, attitudes

1. INTRODUCTION

The Croatian coast has 1246 islands, islets and cliffs [3] and is among the most indented coasts in Europe and the world. According to the latest census in 2011 2.92% of the total population of Croatia lives on the islands [2]. For the island's population, one of the most important factors is public sea transport, as this ensures regular connectivity of the island with the mainland and the islands, without it, there would be no life or sustainable development on the islands.

Coastal passenger transport has an irreplaceable role in economic and demographic development and survival of Croatian islands and as such it has to take into account the needs of the permanent and occasional in-land population. Its development is mainly important to equate the quality of life alignment with those on the mainland, which has a direct impact on the sustainability of life on the islands.

However, passenger traffic on Croatian state maritime lines is constantly increasing, implying the harmful consequence of environmental pollution. Emissions from the maritime transport sector contribute significantly to global air pollution [15] and ships can significantly contribute to the degradation of air quality in coastal areas [13]. According to the International Maritime Organization (2008), marine gas emissions are not well-quantified and are one of the least regulated anthropogenic sources [7]. Consequently, there is an obvious need to undertake maximum efforts to reduce the emissions of pollutants into the atmosphere from the maritime transport sector, and this can not be missed by the system of the coastal maritime traffic system in Croatia. Pollution caused by maritime traffic is an inexhaustible source of research, because a constantly and quality research of this problem is necessary. This paper explores, by methods of analysis, induction, proofing, descriptiveness, observation and statistical method, the possibility of introducing electric ships into the coastal maritime traffic to reduce the negative impacts of the system on the environment. The aim is to formulate better conclusions and to predict the more realistic situation so through the survey the inspected attitudes of the entities implementing the system, namely the shipping companies that service the coastal maritime traffic system, and the public sector employees of this system.

The hypothesis is that the entities mentioned above are aware of the pollution caused by the system of coastal maritime traffic recognize the need for root changes and support the introduction of electric ships into the system, but consider that after the realization of this concrete activity must be financial support of the state.

2. ECOLOGICAL SUSTAINABILITY OF THE COASTAL MARITIME TRAFFIC SYSTEM

The coastal maritime traffic system of the Republic of Croatia comprises 51 state lines (24 ferries, 15-speed boats, and 12 classic shipping lines), which maintenance 14 shipping companies with a fleet of 77 vessels [1]. The shipping companies structure within the system is shown in Table 1. The state-owned company Jadrolinija still dominates in the system because it participates with 86% of total passenger traffic and 89.4% of total traffic.

Table 1. The total traffic of passengers and vehicles on national lines in 2018

Share of passenger and vehicle traffic in 2018.				
Shipping companies	*Passengers*		*Vehicles*	
Jadrolinija	11.827.446	86,0%	3.089.398	89,4%
Rapska plovidba d.d.	898.570	6,5%	365.552	10,6%
KTD Bilan d.o.o	216.444	1,6%		
G&V Line Iadera d.o.o.	188.769	1,4%		
MB Kapetan Luka, Ivan Tomić, t.p.	128.062	0,9%		
Bura Line & Off shore	109.068	0,8%		
Gradski parking d.o.o Šibenik	81.667	0,6%		
RPZ Vrgada	64.742	0,5%		
G&V Line d.o.o.	63.582	0,5%		
Miatrade d.o.o.	60.682	0,4%		
Catamaran Line d.o.o.	59.527	0,4%		
Krilo shipping company d.o.o.	31.222	0,2%		
Porat Ilovik d.o.o.	17.795	0,1%		
Nautički centar Komiža d.o.o.	8.272	0,1%		

Source: Agency for Coastal Maritime Traffic System [1]

Maritime lines coastal maritime traffic system are a continuation of road routes on the mainland and this system is essential for linking the islands and for the island's sustainability, which confirms the constant growth of the number of passengers and vehicles transported, so in 2018 the total number of passengers carried in the coastal Croatian traffic amounted to 13.7 million respectively 3.4 million vehicles [1], what is increase of 1.8% in the number of passengers and 4.9% in the number of vehicles. Table 2 shows the relation between transported passengers and vehicles in 2017. and in 2018. with a note that these numbers are on the uphill route since 2010.

Table 2. Comparison of passenger and vehicle traffic 2017./2018.

Passengers 2017.	Passengers 2018.	Vehicles 2017.	Vehicles 2018.
13.506.173	13.755.848	3.294.172	3.454.950

Source: Agency for Coastal Maritime Traffic System [1]

The country with an expressed index of indented coastline recognizes numerous benefits of the coastal maritime traffic system, but must also take into account its negative effects, especially on the environment, due to the use of diesel engines on ships. Diesel engines characterize a negative impact on the environment due to the emission of harmful gases, an increasingly present problem that all maritime transport stakeholders must face. All 77 ships in the system use diesel engines which do not deviate significantly from the global and European trends.

Maritime traffic releases around 940 million tonnes of CO_2 per year and is responsible for about 2.5% of global greenhouse gas emissions (GHG) [8]. It is anticipated that these emissions will be significantly increased unless measures are introduced to reduce the negative impact of maritime transport on the environment. According to the third IMO study on greenhouse gas emissions, emissions from ships could be increased according to the business scenario from 50% to 250% till 2050 [8]. At the same time, there is a significant untapped potential for economical reduction of ship emissions. By increasing ship traffic, there is an increase in emissions of exhaust gases such as:

- nitrogen oxides (NOx) - their emission effects the formation of smog and acid rain. In the atmosphere with volatile organic compounds and other reactive gases, and with solar radiation, it participates in the creation of ground-level ozone. Nitrogen oxide emissions are constantly increasing as a result of increased traffic; that is, it mostly results from the combustion of any liquid fuel.
- sulfur oxides (SOx) - sulfur dioxide SO2 is known as "acidic" gas because its transformation results in the formation of acidic components that are separated from atmosphere acid rainfall. The SO2 emission depends directly on the quality of the fuel, ie the content of the sulfur in it.
- Carbon monoxide (CO) - a consequence of incomplete fuel combustion, effects the formation of smog and ozone holes. Today's engines have very low carbon monoxide emissions due to high oxygen concentration and efficient combustion processes.
- hydrocarbons (HC) - the carbon content in exhaust gases depends on the type of fuel, tuning and engine construction. Only a small part of HC will leave the process unburned - it effects the effect of the greenhouse.
- Carbon dioxide (CO2) - although not toxic, special attention is paid to it as the root cause of the greenhouse effect [10]. Motors with a high degree of utilization and use of low carbon fuel are prerequisites for reducing the emissions [10].

Emission of exhaust gases from ships into the atmosphere can potentially be detrimental to human health and can also contribute to global warming, all mentioned applies to ships operating the coastal transport system in Croatia and it is necessary to introduce strict measures to reduce its negative effects.

The European Union was among the first to address the root causes of climate change and to seek optimal solutions within the framework of the Paris Agreement, so in November 2018 it was defined that till 2050 emissions of gases should be reduced to zero [5] including maritime traffic. This regulation has begun a race to create new technologies in shipbuilding in terms of better construction design and more efficient design, use of lighter materials for shipbuilding and use of more acceptable alternative fuels, thereby reducing the consumption or reducing harmful emissions in the atmosphere. There are already good examples such as ships in the public transport system in Copenhagen that use biofuels as propulsion fuels or individual ferries in Norway and other countries that use batteries [4].

Since the European Union supports the diversification of propulsion fuels used in coastal shipping using new, more competitive and environmentally friendly fuels, the Republic of Croatia, as an EU member, implementing such fuels would bring international recognizability of the country adopting new technologies. For these reasons, and because of the long-term sustainable development of the Croatian shipbuilding and supporting industry, the entry into this very powerful market niche should be encouraged.

Croatia follows the trends and adjusts to changes, so some of the impressions are already noticeable. In December 2016, the Law on the Establishment of an Alternative Fuel Infrastructure was established, with which setting out the minimum requirements for the construction of alternative fuel infrastructure, with which transposed the provisions of Directive 2014/94/EU of the European Parliament and of the Council of 22 October on the obligation to establish an infrastructure for alternative fuels for each EU Member State [16]. The common framework of measures defined by the Act is implemented through the National Policy Framework for the Establishment of Infrastructure and the Development of Alternative Fuel Market in Transport, which was enacted and adopted by the Government of the Republic of Croatia in April 2017. The national policy framework has defined an assessment of the current state and future development of alternative fuels in the transport sector, including its possible simultaneous and combined use and the development of infrastructure for implementation [9]. Furthermore, according to the Decision on the National Policy Framework for the Establishment of Infrastructure and the Development of Alternative Fuel Market in Traffic, stations for electricity supplies from seaports to ships must be available at Rijeka port by December 31, 2025, so it is evident that the establishment of electricity supply from the mainland to ships in ports is a priority that there is demand and that the costs and benefits, especially the environmental benefit, are in proportional proportions. It is of the utmost importance to include an acceptable development of maritime transport in the National Plan for the Development of Coastal Maritime Traffic, aiming to optimize the network by interconnection, new technologies, the use of alternative fuels in the transport system, and to encourage the development of new, different fleets in the coastal transport system and a more efficient system of subsidies.

The role of the shipping companies in eliminating the negative effects of the system on the environment should not be neglected. The shipping companies take responsibility for the implementation of the system and face many challenges in servicing the coastal maritime traffic system. The most prominent problems of shipping are: the unfavorable age structure of the fleet, the high share of fuel prices in total transport costs and significant seasonal oscillations. Only if shipping companies are willing to invest in new ships with more acceptable propulsion systems or in the conversion of existing ships can be expected changes within the system.

Croatia is developing a path towards more environmentally-friendly solutions in maritime traffic or using alternative fuels, leading the Strategy of Maritime Development and Integral Maritime Policy of the Republic of Croatia for the period 2014-2020, which clearly states that for the purpose of raising the quality and secure long term competitiveness of shipping is necessary to encourage innovation in shipping, as well as procurement and construction of eco-boats or adaptation of existing vessels to high ecological standards [12].

One of the alternatives is electric motors that are already present in the world on some of the ships on short ferry voyages, but there is a need to provide infrastructure in ports where it is possible to supply electricity on land so that ships can connect to it. Although numerous limitations are present, changes are necessary but also inevitable.

3. POSSIBILITY OF INTRODUCING SHIPS TO ELECTRIC POWER IN COASTAL MARITIME TRAFFIC SYSTEM

The fleet of the coastal maritime traffic system in Croatia exclusively uses diesel engines, which do not deviate significantly from the world and European trends. Diesel engines are characterized by thermal efficiency, conceptual simplicity and greater reliability, but also negative environmental impacts due to the emission of harmful gases, an increasingly present problem that all maritime transport participants are faced with. Various legal regulations, raising awareness of this issue, emphasizing the need for responsible business, constant research in this area, seeking measures to maximize harm, point to the search for alternative solutions of the most acceptable types of propulsion fuel. The aim is to limit the negative effects of diesel engines and to find a better substitute. In this context, the use of ecologically acceptable energy sources for vessel propulsion is necessary for the future, but the practical performance of such systems is characterized by high prices, low utilization rate and the need for investment in infrastructure, but there is still no significant representation of ships using renewable energy.

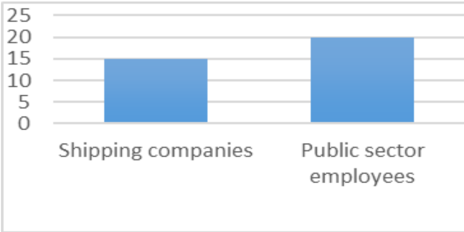
Current trends indicate that these changes will effect to the system of the coastal maritime traffic system in Croatia. There are already small, but significant moves in the framework of the UrbEco project [6]. Namely, the city of Šibenik is the holder of this revolutionary project of ecological shipping on electric propulsion for Šibenik's islands. The aim is to improve the organization of shipping lines in the area so that public transport can maximally raise the quality of life of the population on the islands, implement quality integration of road and sea traffic, as well as introduce electricity boats that have a more favorable impact on the environment, which would be the beginning of changes in the coastal maritime traffic system in Croatia. Of course, it should not neglect the necessity to invest and develop in the infrastructure to achieve the desired result.

The issue of pollution from maritime traffic is increasingly present in Croatia, both through transport and maritime strategies and in the awareness of an increasing number of natural and legal persons. A good example could be the introduction of an electric catamaran in July 2018 in the area of the Mljet National Park. The ship has a capacity of 54 passengers, 15 meters long and 5 meters wide, it is a Croatian product, and is primarily intended for sailing in protected waters where the electric drive reduces the emission of harmful gases into the atmosphere and reduces the noise and vibration generation [11]. There are two more catamarans of the same characteristics and capacity, so existing diesel-powered boats will be completely replaced by new, economical and energy-efficient vessels in this area [11]. The use of electric propulsion has effects on the economic efficiency of the ship because it reduces the cost of exploitation and fuel consumption, improves maneuverability, and increases availability. Therefore, the electric power transmission of a modern ship with electric propulsion is designed to require minimal intervention during the exploitation life of the ship, which is a significant advantage [14].

The mentioned advantages lead to ecological benefits which are a significant advantage that is constantly trying. Much greater safety and lower emissions of ships with electrical propulsion with increasingly stricter regulations will increasingly limit the application of diesel propulsion. However, there is still high investment cost to build a ship with electric propulsion, which will surely change in the future, primarily due to the strong competition between major world producers of marine electrical equipment and production in larger series due to market expansion [14].

In this case, it is an extremely important source of electricity, so it is necessary to make greater use of renewable energy sources to obtain a useful and high-quality product that would achieve the desired result, as most of the energy used in the world comes from limited non-renewable energy sources.

One of the most important factors for realizing the idea of introducing electric ships in coastal maritime traffic system in Croatia are shipping companies, but also the employees of the same sector, because they are active system participants in the function of serving the service and in such a role can accelerate the development of this idea as well as slow down. Therefore, a survey of these groups was carried out in order to examine attitudes and degree of interest in this issue. The survey encompassed 35 respondents, of whom 20 are system employees and 15 are shipping companies representatives, serving the system of the coastal maritime traffic system, as shown in Graph 1.

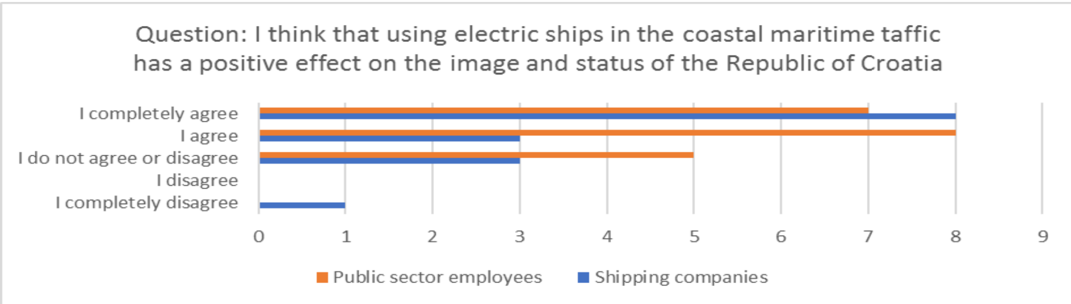


Graph 1 Structure of respondents

Source: Authors

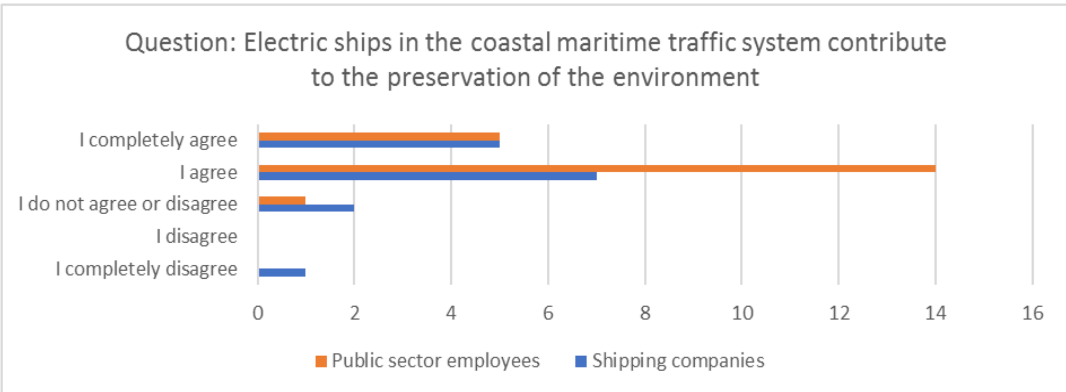
All the data obtained in this survey were processed in the SPSS program, which makes it easier to make concrete conclusions from the research conducted.

Analyzing Graphs 2 and 3, it is concluded that both groups in great measure consider that the introduction of electric vessels into the system contributed to the positive image of Croatia, as most of them believe that electric ships will have a positive effect on environmental protection, which indicates a high level of awareness about this problem.



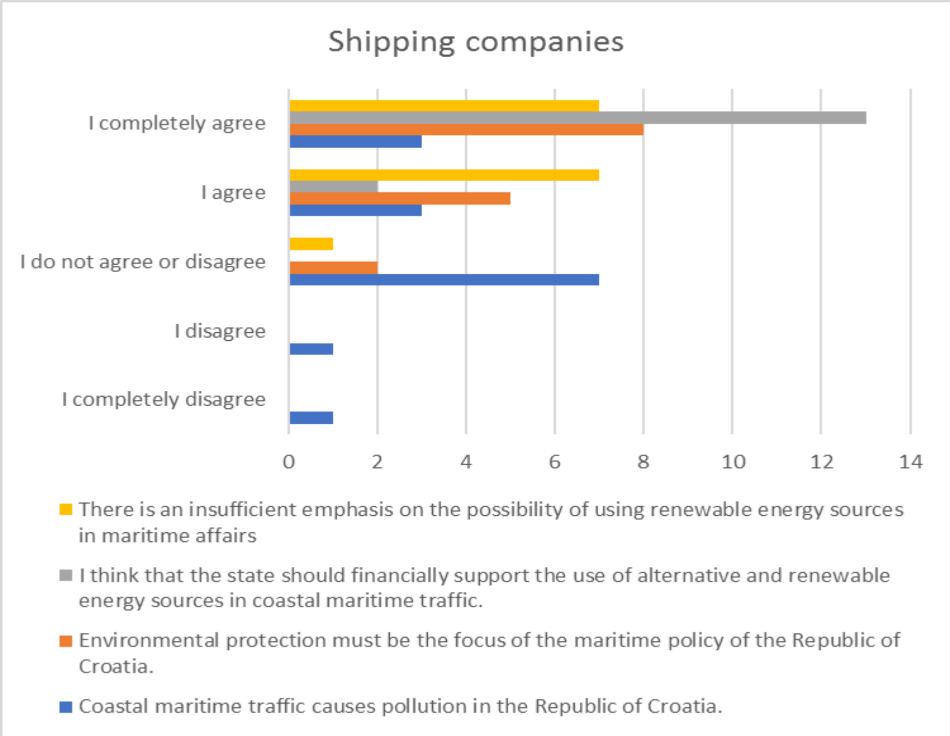
Graph 2 Electric ships regarding the image and status of the Republic of Croatia

Source: Authors



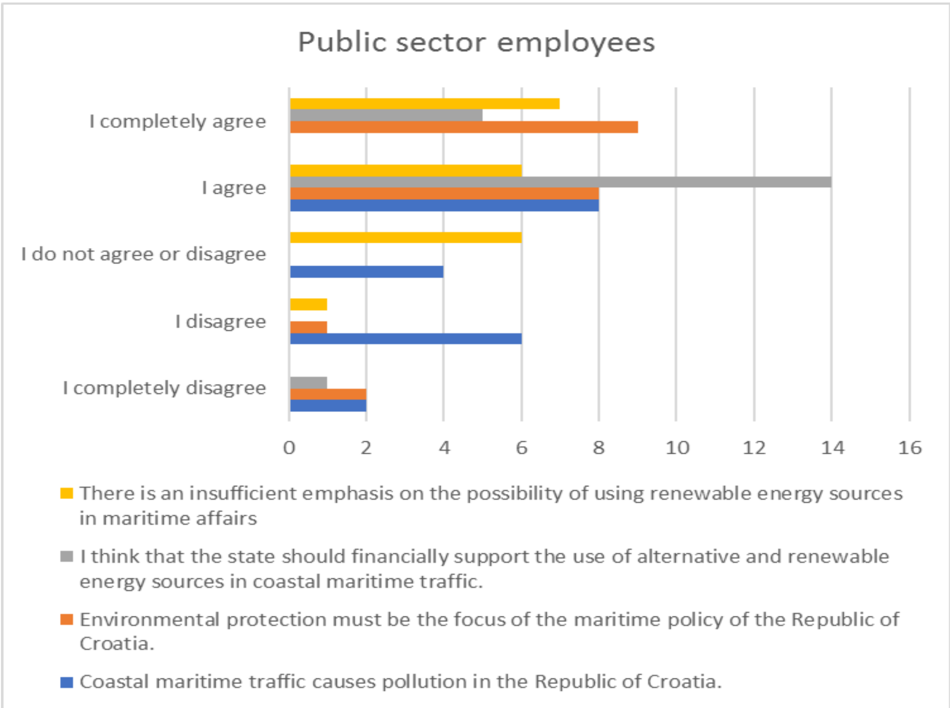
Graph 3 Impact of electric ships on the environment

Source: Authors



Graph 4 The attitudes of shipping companies about maritime traffic and reduction of environmental pollution

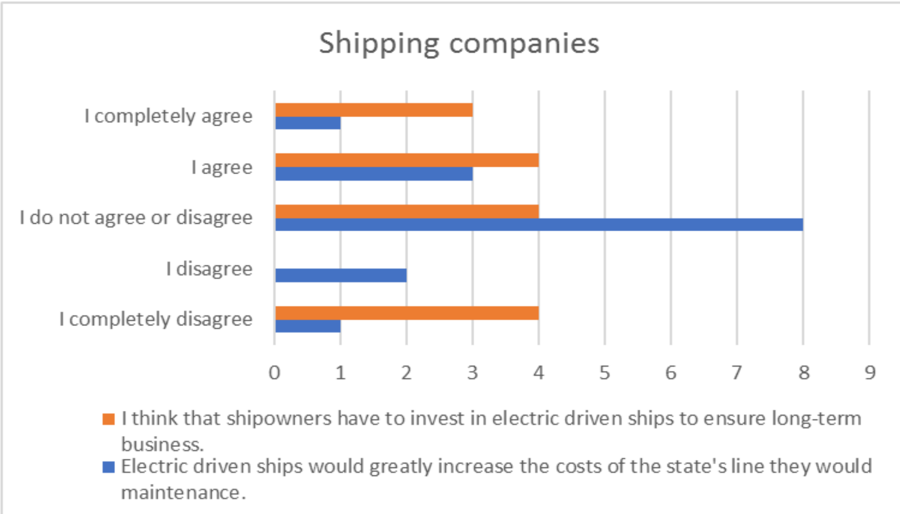
Source: Authors



Graph 5 The attitudes of public sector employees about maritime traffic and reduction of environmental pollution

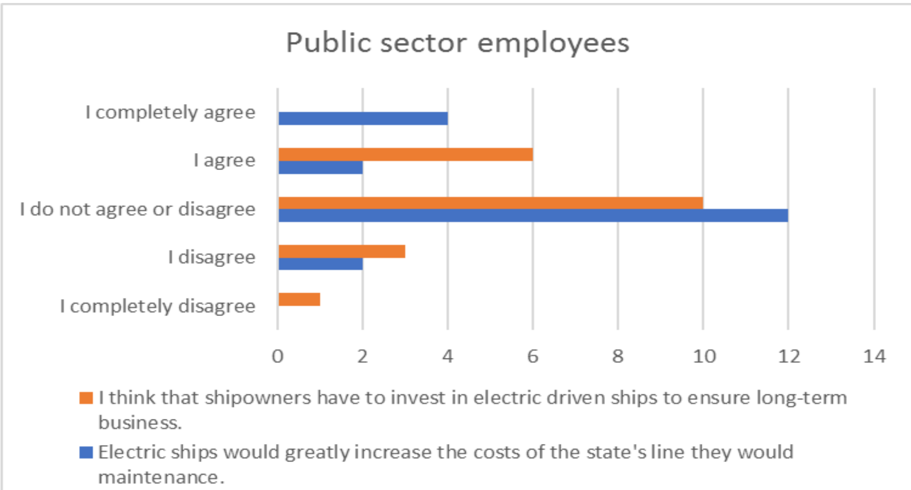
Source: Authors

Graphs 4 and 5 show the attitude of shipping companies and the public sector about this issue, which is the prerequisite for the introduction of this type of vessel into the system. Analyzing their responses collected through the survey, it is concluded that there are significant correlations in their attitudes so that shipping companies and the public sector believe that the state should financially support the use of alternative or renewable energy sources in the system of the maritime coastal maritime traffic system. Shipping companies and most public sector employees believe that the possibility of using renewable marine resources is insufficient, suggesting the need for greater involvement of all entities in the system. It is surprising that a certain part of the public sector does not consider that maritime traffic cause pollution in Croatia as well as that environmental protection must be the focus of maritime policy while shipping companies have no doubt pollution question, but a small number of respondents believe that it is not necessary that environmental protection is the focus of maritime policy.



Graph 6 The attitudes of shipping companies on electric ships and costs

Source: Authors



Graph 7 The attitudes of public sector employees on electric ships and costs

Source: Authors

Graphs 6 and 7 provide answers to questions on the impact of the investments in electric ships for long-term business as an increase in line costs in the case of the use of electric-powered vessels in the system. Considering that significant investments are needed, shipping companies are not inclined to believe that electric ships are necessary for long-term sustainable business, and most public sector respondents have no opinion about it. Also, both groups of respondents do not have a clear opinion on increasing the costs of state lines in the event of the introduction of this type of ships, implying insufficient information and the need for further education and research so that all subjects can have a clear picture of this issue.

4. CONCLUSION

The Croatian coast is characterized by significant indented, which implies a large number of islands, islets, and cliffs. This natural category is bound to connect the island with the land and the islands to each other in order to preserve life on the islands and to ensure the sustainable development of the island. The coastal maritime traffic system is a system without which islands and island's population~~s~~ could not survive, but also this mode of transport, especially with its expansion, negatively effects to the environment. The fleet of the system consists ~~of~~ 77 ships and all ships have diesel engines. Diesel engines are characterized by a negative impact on the environment due to the emission of harmful gases, which is more and more present a problem that all maritime transport operators must face, for what many diesel engine manufacturers, shipbuilding industry, shipping companies, and legislation are working hastily on new solutions to reduce harmful emissions. The goal is a motor of high utilization, profitability, and ecological acceptability. Coastal maritime traffic in Croatia has to adapt to changes and the world and European trends. The largest role has the shipping companies and the public sector as well as employees within the system. The public sector, through the application of various provisions and rules, may encourage the introduction of more acceptable propulsion fuels, and shipping companies that service lines within the system, with their investments and business changes, have a significant role in introducing into the ship's system with more environmentally friendly engines. Changes can not be realized without the support of these two sectors, because they are the system service providers and without them, the system does not exist. For this reason, in this paper, their views on the introduction of ships into an electric drive within the system of coastal maritime traffic system as one of the alternative solutions to the suppression of the negative impact of the system on the environment. The research carried out in this paper points that the observed sectors have a significant level of awareness of pollution caused by maritime traffic and most consider that environmental protection must be in the focus of transport policy, support the introduction of electric ships but also believe that state's financial support is necessary. Both groups consider that this step will influence the better position and image of Croatia. The results of the research confirm the hypothesis set and conclude that the participants in the coastal maritime traffic recognize the problem and that there is an initiative to solve the existing problem. Although the introduction of electric ships requires large investments in infrastructure and ships, there is a desire and need for more environmentally-friendly ships, and thus the basis for the upcoming positive changes within the system of Coastal Maritime Traffic. Electric ships in the system would surely be a new trend, but there are already some good examples in Croatia such as the Mljet National Park or the UrbEco project in Šibenik, so it points to the application of this alternative path shortly.

REFERENCES

[1] Agencija za obalni linijski pomorski promet, http://www.agencija-zolpp.hr/Po%c4%8detnastranica/tabid/1251/Default.aspx, (accessed 15 May 2019)

[2] Croatia Bureau of Statistics (2011), https://www.dzs.hr/Hrv/censuses/census2011/censuslogo.htm, (accessed 03 May 2019)

[3] Duplančić-Leder, T., Ujević, M. i Viđak, I. (2000) *Categorization and number of islands in the Republic of Croatia*. Periodicum Biologorum. Vol.102. Suppl 1. pp. 281-284

[4] European Environment Agency, Aviation and shipping emissions in focus, https://www.eea.europa.eu/articles/aviation-and-shipping-emissions-in-focus, (accessed 13 May 2019)

[5] Europska komisija, Bruxelles (2018), Europska strateška dugoročna vizija za prosperitetno, moderno, konkurentno i klimatski neutralno gospodarstvo, Komunikacija Komisije Europskom parlamentu, Europskom vijeću, Europskom

gospodarskom i socijalnom odboru, odboru regija i Europskoj investicijskoj banci, https://eur-lex.europa.eu/legal-content/HR/TXT/PDF/?uri=CELEX:52018DC0773&from=EN, (accessed 25 May 2019)

[6] Grad Šibenik, http://www.sibenik.hr/urbeco/index.html, (accessed 01 June 2019)

[7] International Maritime Organization (2014), Amendments to the Annex of the Protocol of 1997 to Amend the International Convention for the Prevention of Pollution from Ships 1973 as Modified by the Protocol of 1978 Relating thereto (MARPOL Annex VI), http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Marine-Environment-Protection-Committee-(MEPC)/Documents/MEPC.247(66).pdf, (accessed 01 June 2019)

[8] International Maritime Organization, http://www.imo.org/en/Pages/Default.aspx, (accessed 12 June 2019)

[9] Lopac, A. A. (2017) *Mogućnosti primjene ukapljenog prirodnog plina u pomorskom i kopnenom prometu Republike Hrvatske*. Nafta i Plin. Vol. 37. No 152. pp. 62-71

[10] Milošević – Pujo B., Jurjević N. (2004) *Onečišćenje mora iz zraka emisijom ispušnih plinova*. Naše more. Vol. 51. No 5-6. pp. 178-184

[11] Nacionalni park Mljet, http://np-mljet.hr/predstavljanje-novog-elektricnog-broda/, (accessed 01 June 2019)

[12] Strategija pomorskog razvitka i integralne pomorske politike Republike Hrvatske za razdoblje od 2014. do 2020. godine, https://mmpi.gov.hr/, (accessed 10 June 2019)

[13] Viana, M., Hammingh, P., Colette, A., Querol, X., Degraeuwe, B., de Vlieger, I., van Aarenne, J. (2014) *Impact of maritime transport emission on coastal air quality in Europe*. Atmospheric Environment. Vol. 90. pp. 96-105

[14] Vučetić, D., Čekada, I. (2006) *Eksploatacijske prednosti električne propulzije.* Pomorstvo. Vol. 20. No 1. pp. 129-145

[15] Wang, C., Corbett, J.J., Firestone, J. (2008) *Improving spatial representation of global ship emissions inventories.* Environmental Science and Technology. Vol. 42.1. pp. 193-199

[16] Zakon o uspostavi infrastrukture za alternativna goriva, NN 120/16, https://www.zakon.hr/z/891/Zakon-o-uspostavi-infrastrukture-za-alternativna-goriva, (accessed 01 June 2019)

A NEW E-PLATFORM FOR SUCCESSFUL LEARNING OF COLREGs

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34779*656.61

Summary

The Faculty of Maritime Studies in Rijeka was the leader of the European Union project "Avoiding Collisions at Sea" (ACTs). The project started on November 2013 and ended by November 2015. The purpose of this project was to identify skill gaps in knowledge and teaching of COLREGs (*International Regulations for Preventing Collisions at Sea 1972 - Rules*) for nautical students and maritime professionals and non-professionals. Project research results clearly showed lack in understanding of some parts of COLREGs due to wrong interpretation and application of the Rules. The only way to change this in the future was to improve learning methods of COLREGs. In order to archive improvement on-line COLREGs course was prepared. In this e-course there are over 280 scenarios explaining the Rules, available in English and in 5 different languages including Croatian, Spanish, Turkish and Bulgarian. Since the e-course was uploaded it has been used for 4 years all over the World. In total there were over 200,000 session with duration over 15,000 hours. E-course has been used for the past 4 years at Faculty of Maritime Studies University of Rijeka COLREGs classes and the results show significant improvement in students' knowledge and understanding of the Rules.

Keywords: COLREGs, eLearning, eCourse

1. INTRODUCTION

COLREGs rules are, considerably, one of the oldest conventions that still apply in the original form since adoption. However, beside small amendments, these Rules are the same as in 1972 and since than seafaring had changed. Also, the number of the vessels at sea increased which affects the risk of collisions at sea. The sailing speed of vessels is also changed, especially with the high speed crafts, large container vessels and passenger vessels. This increment in speed reduces time for navigator to properly asses and react in situations when risk of collision exists.

Since then, also the devices at the navigation bride changed. Radar with ARPA is now most usual device with the great amount of accuracy and greatly changed since COLREGs convection was adopted. This applies to great leap in computing power of ARPA unit and technical advancement. In addition to ARPA, most of the vessels have AIS device which improves detectability of other vessels. Great improvement has been done in areas of charts and determining vessel positions. This is now all provided with ECDIS which has electronic charts where the vessel position is displayed all the time. In many area where traffic is congested VTS service has been established in order to provide safe passage and to avoid risky situations. This technical improvement is great however it is not perfect and still has its flaws.

As the COLREGs convention is such that is it hard to make changes, other way to reduce collisions at sea is to affect Rules knowledge in order to improve understanding and proper application of the Rules. For that reason ACTs (Avoiding Collisions at Sea) project was started. The project started in 2013 and had a goal to prepare an online course which would improve knowledge and understanding of the Rules. To achieve that, the team from six EU countries was gathered and many workshops and questionnaires with students, deck officers, masters, VTS operators, marine pilots, etc. were organised. The common conclusion from initial research phase was that the Rules are hard to understand and need update. With that conclusion eCORLEGs course (www.ecolregs.com) was prepared. The course is available online at six different languages, explaining the Rules with 283 scenarios using bridge view, radar view, birds' eye view and where applicable ECDIS view in order to help students and seafarers to correctly understand and apply the Rules. Project finished in 2015 and since then more than 200,000 users all over the world visited course and spend over 15,000 hours browsing scenarios.

2. RESEARCH RESULTS AND eCOLREGS COURSE

In order to gather general opinion and knowledge of the Rules questionnaire was prepared. This questionnaire was prepared in such manner to test participant knowledge and understanding of the Rules and to see how do they apply them. Questionnaire was available from January 2014 and in period of three months over 1200 participants were recorded. By the January 2015 in total there were 1500 participants in survey. Participants' structure was diverse by age, seagoing experience and current occupation (Figure 1) [1].

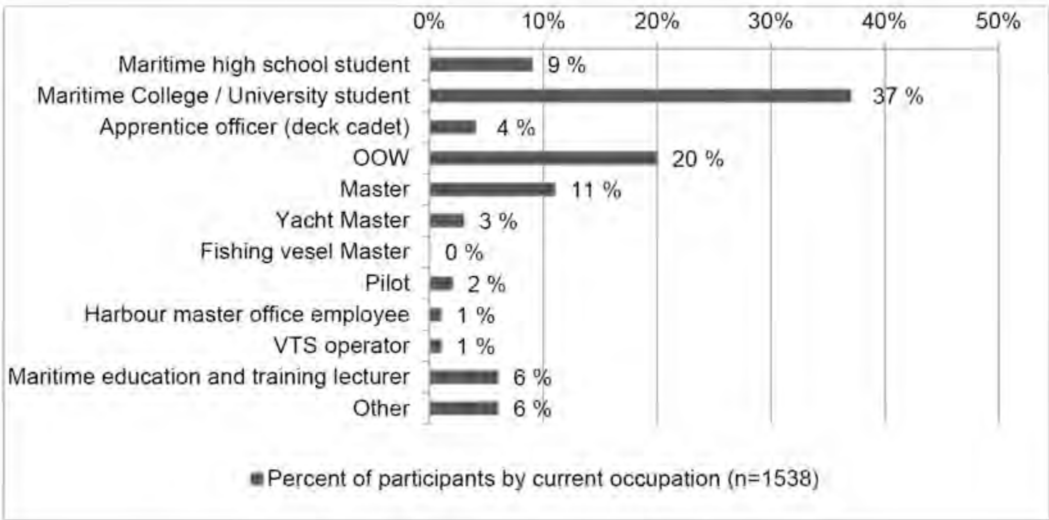

Figure 1 Participants structure by current occupation

Source: [1]

To test questionnaire reliability one part contained test of the Rules knowledge and understanding and other part contained questions which queried participants in a manner to point out what Rules are hard to understand. In Figure 2 are results from the part of testing Rules knowledge and understanding and in

Figure 3 are results from the part where participants pointed out which Rules are hard to understand. In order to properly interpret the results the participant are divided in two groups, depending if they have or don't have any seagoing experience.

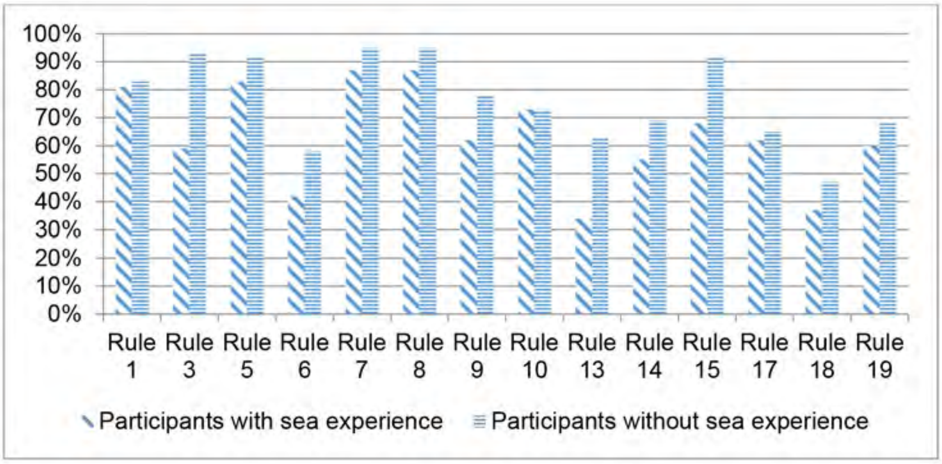

Figure 2 Results from the part of testing Rules knowledge and understanding

Source: [2]

If we compare the results from Figure 2 and Figure 3 it can be concluded that Rules which have the least correct answers are also marked as Rules which are hard to understand. That significant correlation is present in Rule 6, 9, 10, 18 and 19. Such result indicate that improvement needs to be done in order to improve Rules knowledge and understanding, regardless of seagoing experience.

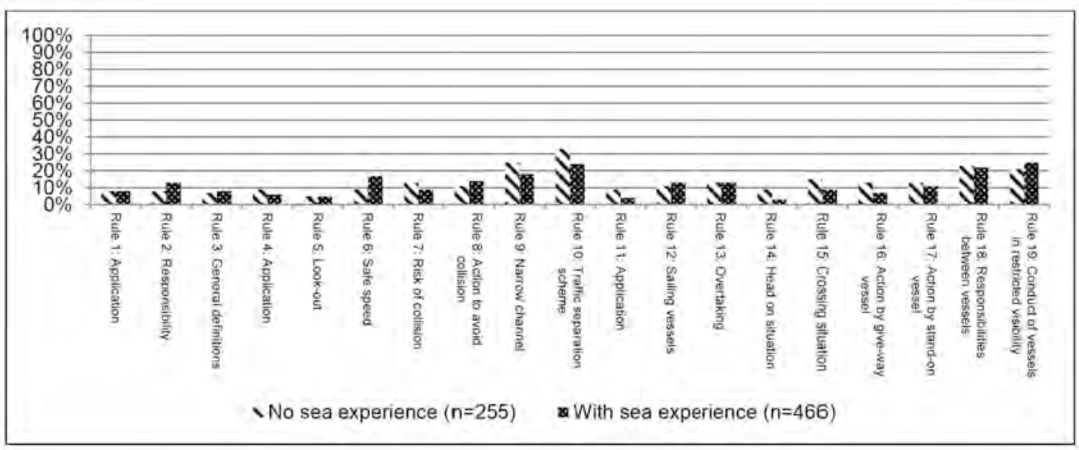

Figure 3 Rules which are hard to understand, according to participants answers

Source: [2]

The best way to access all groups of users is online course. Such platform enables users' usage at desired pace and in desired time. Platform is divided in same manner as COLREGs convention which enables easier managing trough the course. Every Rule is explained trough scenarios (Figure 4) and every scenario explains each paragraph. Scenarios are designed and explained as a real situation at sea. That situation is described textual, graphical with the image of situation and using videos which are recorded on Transas navigational simulator (Figure 5). Those videos are bridge view, radar view, birds eye view and ECDIS view (ECDIS view is only given for scenarios in congested waters) [2].

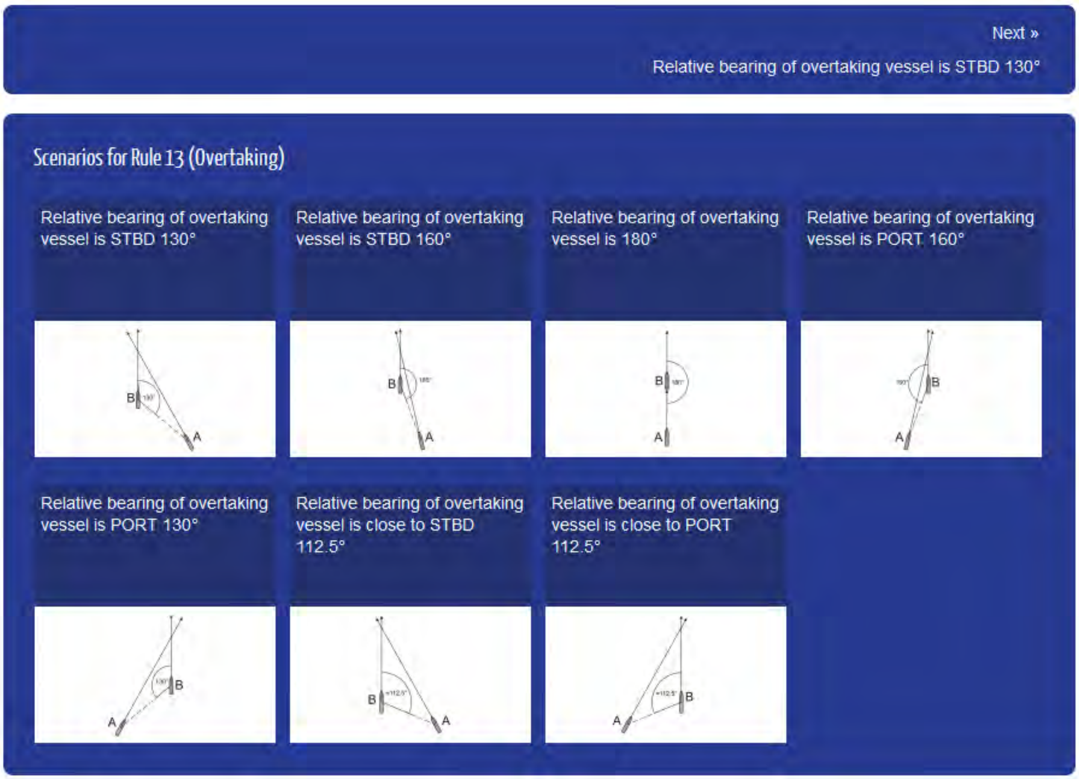

Figure 4 Example of scenarios for given Rule

Source: [3]

Also, where needed specific Rule is additionally commented and specific actions are shown which help improving application of specific Rule. Whole course is evaluated through internal evaluation by expert team. After internal evaluation external evaluation and pilot testing was conducted. In that phase 48 professionals and 107 students tested course and pointed out what needs to be corrected. After that course is released on-line as public and free of charge.

Rules regarding lights, shapes and sound signals are also included. Those Rules, beside standard illustrations of vessel lights and signals, have 3D adjustable image of vessel lights (Figure 6). That approach enables better perception of that part of the Rules and eliminates any doubt if ever existed regarding lights, shapes and sound signals.

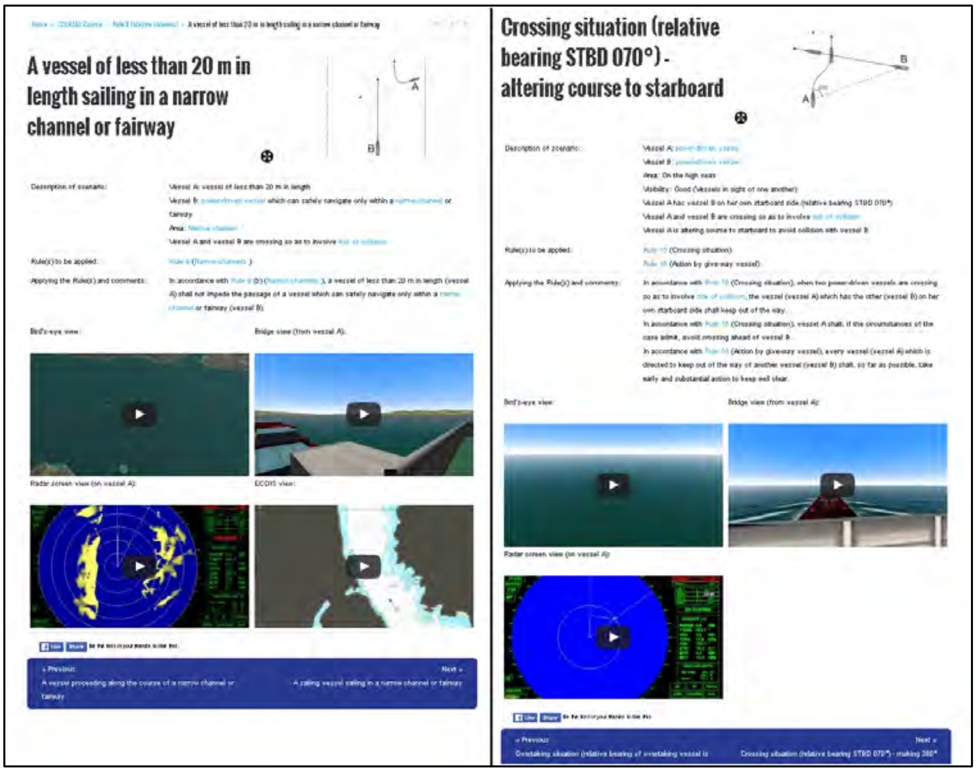

Figure 5 Specific scenario describing situation for specific Rule part

Source: [3]

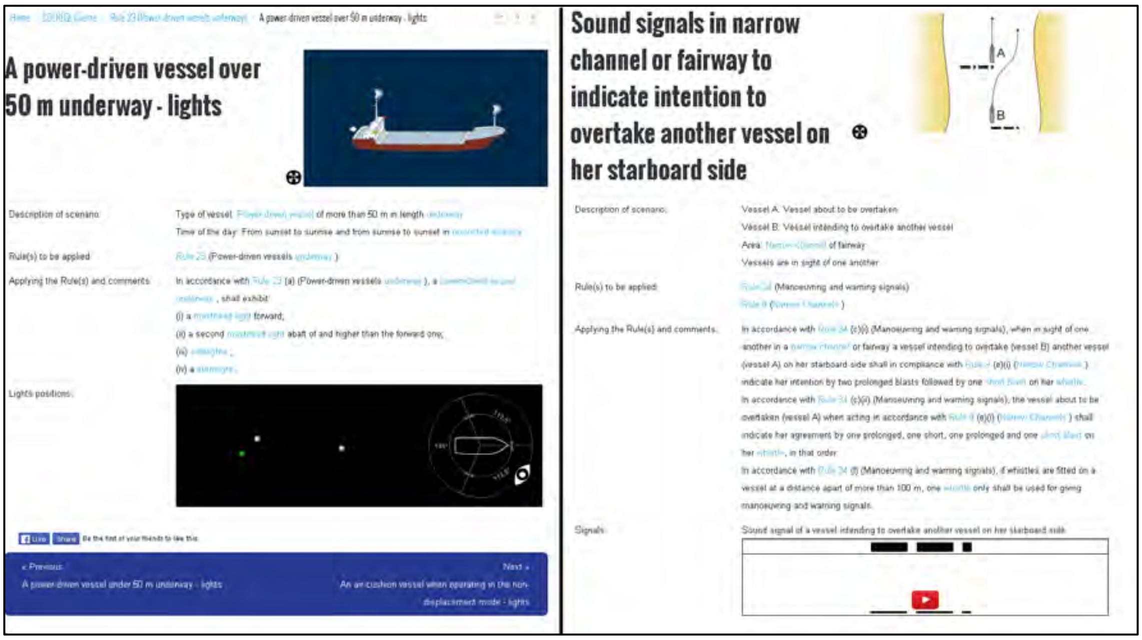

Figure 6 Scenario representing lights and sound signals

Source: [3]

3. RESULTS OF ECOLREGS COURSE IN PRACTICE

This course has been used at Faculty of Maritime Studies Rijeka as a part of regular classes on subject Ship Maneuvering since 2015. The online course used as a visual aid during lectures to demonstrate what professor explained. In order to perceive if the course had any benefit examinations results from 2009 to 2018 were analyzed. In that time period 872 students enrolled in this subject and in average 50% of them passed the exam. However, if that result is divided by the year it can be seen that percentage is higher after 2015 (Table 1).

The improvement in student knowledge and understanding can be observed trough grades. This exam is conducted orally so the professor grade reflect true student knowledge. In analyzed time period, the best grade (5) increased by 30 % and the lowest grade (2) is reduced to 0%. That means that students which take exam are better prepared and truly understand the subject (Table 2).

Table 1 Results of Ship Maneuvering course from 2009 to 2018

Academic year	Number of students evaluated with more than 1		Average grade per year
	Number	Percentage	
2009/2010	26	43 %	3,154
2010/2011	50	53 %	3,220
2011/2012	42	38 %	3,107
2012/2013	50	48 %	3,970
2013/2014/2015	71	47 %	3,937
2015/2016	57	52 %	4,167
2016/2017	73	55 %	3,960
2017/2018	59	56 %	4,019

Table 2 Percentage of students grades from 2009 to 2018

Grades	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014/2015	2015/2016	2016/ 2017	2017/2018
5	8 %	12 %	7 %	36 %	37 %	47 %	34 %	39 %
4	42 %	38 %	28 %	44 %	35 %	40 %	41 %	37 %
3	42 %	42 %	55 %	20 %	27 %	11 %	25 %	24 %
2	8 %	8 %	10 %	0 %	1 %	2 %	0 %	0 %

It can be concluded that since 2015 passing percentage and grades are better than earlier years. However, this needs to be linked with the usage of eCOLREGs course. That can be made through course usage statistics. First, number of sessions is analyzed in time period from 2015 to 2018. In that time period, especially during COLREGs exam schedule (December, January and February) significant increment in number of sessions can be detected (Figure 7).

Figure 7 Number of sessions since 2015 to 2018

Source: [3]

This clearly indicates that the course was significantly used for preparing exams and can be concluded that eCOLREGs course fulfilled its purpose. That is also confirmed with the data of average session duration, where it is noticeable that users from Croatia have the longest sessions (Figure 8). However, statistics show that second place in session duration and first place in session number hold users from

Philippines. That country was not part of the project and without any promotion this course was recognized. This course, is used all over the world as one of the best courses designed for learning COLREGs rules.

	Country	Number of sessions	Duration of Sessions
		214,384 % of Total: 100.00% (214,384)	15486:27:07 % of Total: 100.00% (15486:27:07)
1.	Philippines	32,046	14.59%
2.	United Kingdom	19,204	6.49%
3.	Turkey	16,675	6.03%
4.	India	15,185	5.61%
5.	United States	14,450	3.14%
6.	Croatia	11,215	17.67%
7.	Bulgaria	7,079	5.22%
8.	Australia	6,018	2.36%
9.	Singapore	5,847	2.43%
10.	Ukraine	5,058	2.15%

Figure 8 Number of eCOLREGs course users and average session duration from 2015 to 2018

Source: [3]

The work didn't stop on this project. In 2017 another project started (ACTs Plus) which coped with the advanced collision situation which are not described in COLREG rules. Such situations are encounters between more than two vessels and encounters in special areas such channels, traffic separation schemes, etc. The result of the project is similar ecourse, which hopefully will help students and professional seafarers to properly apply the Rules and to reduce number of collisions at sea.

4. CONCLUSION

Present and most likely future students are constantly on line and rely on internet sources. COLREGs rules in original have no images and explanations. Using visual aids and putting the specific rule in perspective (specific scenario) helps the user to understand the essence of that rule. Online course enables user to access it when he desires and learns the Rule at his pace. Combining the ecourse with classes gives another advantage. As the professor uses ecourse material as visual aid during classes eliminates the need for taking notes, because the student can later access those materials. This also improves student concentration and focus. All of that is confirmed with the exam results and ecourse usage. Users all over the world use this course as a tool for better understanding of the COLREGs rules, not only students but professionals which check their knowledge if it is correct. This is the best tool for preventing collisions at sea because it is no restrictive and based on disciplinary responsibility, but improves the knowledge and proper application of the Rules.

REFERENCES

[1] Mohovic, D., Mohovic, R. and Baric, M., 2016. Deficiencies in learning COLREGs and new teaching methodology for nautical engineering students and seafarers in lifelong learning programs. *The Journal of Navigation*, *69*(4), pp.765-776.

[2] Mohović, Đ., Barić, M. and Mohović, R., 2016, January. Innovative way of teaching COLREGs. In *7th International Conference on Maritime Transport*. Barcelona : BarcelonaTech, 2016. pp.125-130.

[3] www.ecolregs.com

SEAPORT AS A STIMULATOR OF THE DEVELOPMENT OF INTEGRATED LAND-SEA TRANSPORT CORRIDORS

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UDK 656.615:656.02

Summary

When assessing seaports, we can point to a number of aspects of their operation, significance in transport systems, supply chains or regional development. In this article the author focused on one of the above broad issues regarding of seaports. These aspects of their functioning have been presented, which affect the shape of the land-sea transport corridors. The corridors, where the seaport should be one of the key structures creating integrated, fixed and multimodal cargo flows. The content presented in the article is the result of research carried out by the author, within which both literature on the subject, professional experience of the author and case studies were used. The research, the effect of which was to classify the key factors, qualitative and quantitative, determining the strength of the seaport forcing the creation land-sea transport corridors. The factors described are, among others, in the areas concerning the transport accessibility of the seaport, the level of development of the objective and spatial functions. These factors are also related to the seaport management system and its development strategy as well as development strategies implemented by port users. The article points out, inter alia, factors related to: the level of development of the seaport infrastructure and transport infrastructure ensuring access to it, the level of development of the functional segment of the seaport and its strategic and operational integration with shippers and the external transport, forwarding and logistics sector. Also indicated are factors that are the result of the development policy of countries or regions, for example UE policy. Due to the fact that the element of the research process was the analysis of the functioning of selected seaports in terms of key qualitative and quantitative factors necessary for the seaport to stimulate the development of integrated land-sea transport chains, the article presents of the results of some case studies that was realized during the research process.

Keywords: seaport, transport corridors, multimodal cargo flows, factors

1. INTRODUCTION

European seaports of the EU TEN-T network are multi-faceted and multi-structured systems consisting of spatial and functional segments. Jointly they create a specific socio-economic space with impact extending the administrative boundaries of the seaport. In this space there are a number of institutions and enterprises connected with each other by legal and civil law relations. Institutions and enterprises, acting in the network system of connections, create potential capable of implementing a series of processes for people, cargo / goods, cargo units and means of transport. The size of the aforementioned processes depends on many external and internal factors affecting the development of the seaport and thus it's both segments. Key factors determine whether a given seaport has the ability to develop objective and spatial functions that allow cluster in its space a number of transport chains and as a result stimulate the development of land-sea transport corridors.

The aim of the article is to present the results of research defining the key factors determining the stimulation of the development of integrated land-sea transport corridors by the seaport. In the research process, using both the literature of the subject, the method of observation, and materials concerning the operation of several dozen European seaports, the scientific approach (subject literature) as well as empirical were combined. Therefore, the research results reflect current methods of managing seaports in Europe. Both at the level of managing the port as a whole as well as at the level of individual companies of the functional segment. The research process was based on system analysis, cause and effect analysis as well as comparative analysis allowing to compile a series of empirical and scientific information.

2. SELECTED ASPECTS OF THE SEAPORT FUNCTIONING

The spatial and functional layout of the seaport is a structure where the spatial and functional segments are indispensable for the implementation of economic processes. The spatial segment of the port, which forms the water area and territory together with the necessary infrastructure, are the elements of technical utilities that determine the potential reloading, distribution, logistics and industrial capabilities of the seaport. It also includes elements of the transport infrastructure, which are subject to the "rigors" of state interests in the segment of economic policy, including transport policy. At this point, it is not important whether the infrastructure located in the territory of the port is state-owned or communal (private property is rare). In today's concept of statehood, the core seaports of the TEN-T network are an element of the transport and logistics infrastructure of the state, hence their water area and access infrastructure are always state-owned and as such not subject to trade.

An equivalent element of the spatial and functional system is the functional segment implementing a series of functions related to the operation of the seaport (objective functions) and its impact on the environment (spatial functions), all processes related to economic and social activity of the seaport. The functional segment of the sea port is the one whose scope and range often goes far beyond the administrative boundaries of the port, deciding on the economic development of port areas and implementation of specific functions related to socio-economic impact on the port environment, as well as its links with the hinterland and foreland, thus creating the place of a sea port in cargo transport chains.

At the same time, in the model approach in each of the ports two spheres can be distinguished [2]:

- administrative and management, the tasks of which are related to the management of the port or seaports,
- exploitation and service, which implements operational and service processes in the space of the seaport as well as production processes.

These spheres create a series of connections necessary for the efficient implementation of economic processes occurring in the port space. A significant part of these connections is the effect of applicable legal provisions imposed on the public sector, managing entities, port users the obligation to carry out economic processes in accordance with them. The rest result from the organization of the port's operation, its generation and civil-legal links between both areas and within them.

The administrative and management sphere is generally composed of institutions and enterprises appointed by state or local government administration. The arrangement of this sphere depends on public regulation being an element of the concept of each country related to its maritime policy, including the port policy [4]. Therefore, it can be created by various institutions and enterprises mentioned above. For example, in European countries, this sphere is created by: maritime administration, port / port managing entities, i.e.

port management boards[1], customs administration, phytosanitary authorities, control and supervisory institutions at various levels (state and local government).

On the other hand, enterprises operating in the sphere of operation and service of the seaport can be divided into: transshipment companies, operators, forwarding, logistics, control and agency services. Carriers, various types of service companies (servicing) of transshipment companies, operators and carriers also operate in this sphere. Its element is also production and processing companies as well as financial, insurance and certification enterprises creating a number of organizational, operational, technical and capital connections. Conducting various activities related to the service of passengers, cargo / goods, transport units and means of transport, they enter into operational and civil-legal links with organizational units of the administrative and management sphere as well as the surroundings of the seaport.

In the literature on the subject, different definitions of seaports can be found. They differ depending on the perception of the seaport either in the context of the place in socio-economic systems, or its economic, technical or social aspects. For example, in accordance with Regulation (EU) 2017/352 "'maritime port' means an area of land and water made up of such infrastructure and equipment so as to permit, principally, the reception of waterborne vessels, their loading and unloading, the storage of goods, the receipt and delivery of those goods and the embarkation and disembarkation of passengers, crew and other persons and any other infrastructure necessary for transport operators within the port area" [14]. In turn, according to Grzelakowski & Matczak, the seaport is: "a spatially large economic area located at the interface of the land with the sea with a complex structure of activity, mainly of a transport, commercial and industrial character, prepared in terms of technical and technological, organizational and administrative, and legal and economic aspects for servicing sea and land means of transport as well as performing other transport, logistics, forwarding and commercial activities, entailing the necessity of their comprehensive service in the transport chain and the supply chain." [4]. The author of an article defines the seaport widely too, indicating that *seaport is a socio-economic space of the multi-faceted impact on the environment combining the processes of transport, thanks to the technical and technological equipment, the sea to the mainland, which are realized interpenetrating, interdependent and interrelated, objective and spatial functions related to with trade and movement of people* [9].

While the definition of a seaport contained in the EU Directive [14] emphasizes the transport nature of a sea port, the definitions of Grzelakowski & Matczak and the author indicate that nowadays the seaport is not only a transport hub but a space within which it is possible to implement a wide range of service and production processes. A significant part of the TEN-T base ports are multifunctional economic spaces, which are not only part of transport systems but also metropolitan areas [8, 9, 18], the production sector and finally the global / regional network of supply chains [15]. Seaports are predisposed to such a multifunctionality due to the extensive spatial and functional layout, where in particular the functional sector plays a special role in entering the seaport into the above-mentioned systems and areas. The key to such a port's operation is its clustering, which allows the creation of many links between organizations (enterprises and institutions) of the functional segment to implement various activities expected by the surrounding seaport.

3. SEAPORTS IN THE NETWORK SUPPLY CHAIN SYSTEM

Figure 1 presents a schematic of a seaport from generation I (up to the 1950s) to III-V (final years of the twentieth century and now), evaluating for years from a transport hub with a strong maritime character to an integrated logistics center or logistic platform [9, 17, 16]. Seaport with developed objective functions: transport, industrial, commercial and logistic-distribution. Especially the latter is characteristic of seaports III-V generation [15, 16], which in the evolution process evolved into multifunctional economic spaces with a

[1] The ownership arrangement of port managing entities depends precisely on the port policy implemented by the given state. The owners of ports' management in Europe are: Treasures of the State, local governments at various levels, including especially urban, private companies. In this respect, there is a variety of solutions in Europe that result from the historical development of ports and a long-term maritime policy

wide impact on the environment (spatial functions), acting as an integrated logistics center in the network system of supply chains.

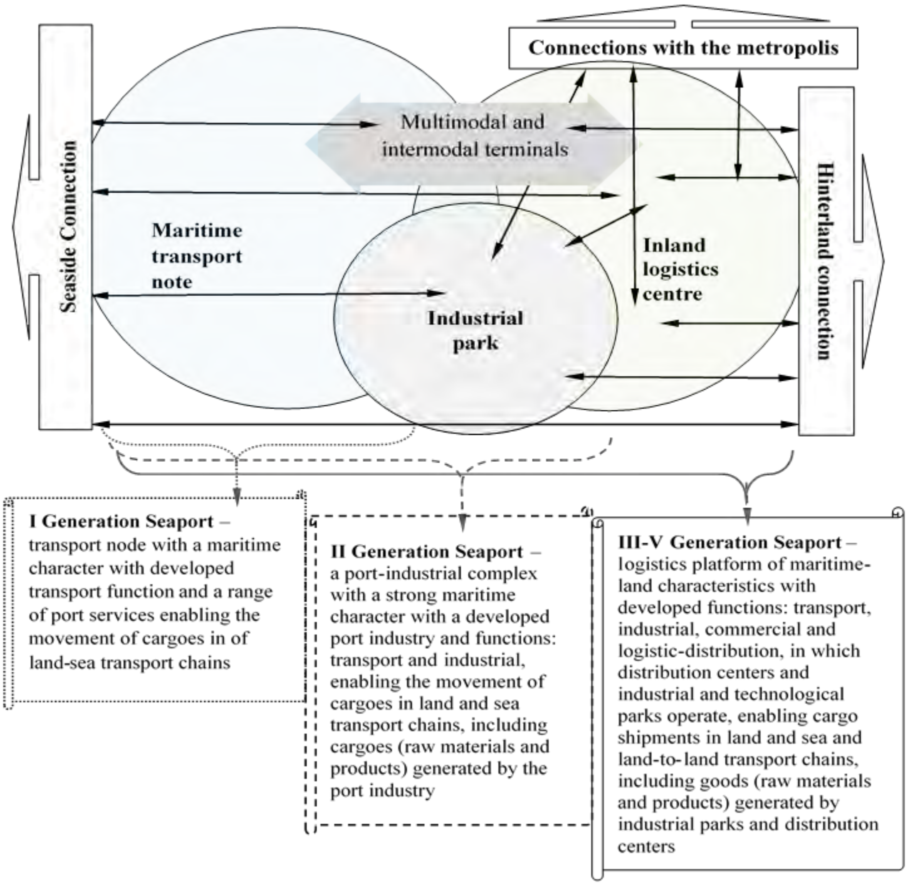

Figure 1 The evolution of the seaport of transport node for the logistics platform

Source: Own source

The seaport diagram presented in the figure, consisting of three key fields of economic activity, illustrates the transformation of seaports, which was a response to changes in the environment, especially those related to containerization and the creation of the global supply chain system (SCS) [6]. These changes have led to the inclusion of seaports in global and regional network supply chain systems, which is natural in a situation where sea transport accounts for almost 90% of global trade [3]. This, in turn, influenced the functioning of the functional segment of the seaport, including the adoption of a philosophy that underlies the strategy of shaping them, where decisions in the supply chain are the result of the final customer's decision [12]. Similarly with seaports. The functional segment has become a technical and organizational element of supply chains, adapting its organization, scope and form of operation to customer expectations. In this case, shippers, logistics operators or shipowners and land carriers, who constitute a key group of both customers and seaport users. The clustered operating system of the functional segment, the inclusion of a seaport into the world container transport system, fulfilling the role of a maritime or land hub, a wide range of logistic services, computerization are the characteristics of seaports IV and V generation. The literature on the subject analyzes the issues related to the above, defining the dominant features of ports of different generations and their role in the global system of supply chains. Examples of the UNCTAD study from 2004 regarding fourth generation ports [15], comparative analysis of ports IV and V of Lee and Lam generation [7] or the definition of ports of different generations (I-V) by Hlali and Hammami [5]. Wide reflections on the forms of operation of seaports and their role in supply chains, including in the flows of containerized cargoes illustrates the importance of seaports in the global trading system.

As already indicated, sea transport has almost 90% share in the global trade in goods, which means that the main cargo flows, being the effect of world trade, run between the main areas of production and consumption located on different continents. One of such areas, both in terms of production and consumption, is Europe and European Union. That means a significant exchange of goods with countries located on other continents. Therefore, maritime transport is one of the key elements of the EU transport system. 74% of goods imported and exported from the Union and 37% of internal exchanges go through seaports [13]. The significance of seaports in the EU transport system is demonstrated by the fact that the total transshipment (handling) of EU seaports in 2017 exceeded 4 billion tonnes [19] and TEN-T includes 329 seaports (as of 2014), most of which are element of the TEN-T Core Network Corridors & Ports [13]. Corridors that are part of the EU concept of sustainable transport development and the basis for investing in transport infrastructure located in these corridors. However, the choice of the goods transport route, including the seaport, if it is referred to land-sea transport chains (element of the supply chain), belongs to shippers, forwarders or logistic operators. Their decisions as to the route of cargo transport depend, among other things, on the accessibility of the seaport, or on the quality and breadth of the range of processes (services and production) offered by a given seaport. This means that the seaport, operating as a multifunctional economic space, as illustrated in Figure 1, naturally becomes a place of concentration of cargo in a global / regional system of supply chains.

4. SEAPORTS AS A KEY ELEMENT OF TRANSPORT CORRIDORS

Changes in the techniques of transport, handling and storage of cargo, which initiated the introduction of large containers into maritime transport in the 1960s, became the basis for the implementation by Eurostat, for statistical and analytical purposes, of a new methodology for assessing land-sea cargo traffic. Land and sea freight was divided into 5 type of cargo (in brackets, to illustrate the issue, transshipments of EU ports in the third quarter of 2018 - in Mio tonnes) [20]:

- Liquid bulk goods (368,6),
- Dry bulk goods (225,4),
- Large containers (228,6),
- Ro-Ro Mobile units (125,3),
- Other general cargo (58,5).

The methodology used by the European Union for the division of cargo in the land and sea transport takes into consideration the methods of transport, handling and storage of cargo recognizing that its physicochemical features, especially in the case of transport in containers or rolling units, are secondary in the context of applied techniques. Thus, it is the technical and organizational side of the transport process that decides about the inclusion of a given good in a particular load category. The adoption of the principle that the method of land-sea transport, transshipment, storage of cargo unit is the key for the implementation of processes, is the effect of containerization and the organization of transport systems, under which different techniques of inter-branch integration are used to increase land and land-sea transport chains efficiency. An especially important place for achieving this efficiency in inter-branch transport is the seaport.

The data presented above (for the third quarter of 2018) on the reloading of the Union seaports show the importance of rolling units for the turnover of ports. In total, these two groups of cargo categories are more than 30% of the total turnover of ports in the EU. This confirms the author's earlier statement that in transport processes of many loads it is important how the load is transported and not its physicochemical features. Certainly, this is a certain research simplification because it is known that in the case of dangerous goods carried in the ITU[2] (large container, semitrailer, swap body, track) information about the load must be posted both on the transport unit and in the transport documents. Nevertheless, when reading port statistics on container turnovers or rolling units, it can be found what loads are being transported, because this is not

[2] Intermodal Transport Unit

de facto significant for the operator of the container or ferry terminal. It is essential for this operator how to organize the transshipment, storage, acceptance or release of the transport unit and other services related to the transport of cargo at the ITU.

Fundamental changes in transport systems in the last 70 years (containerization, development of intermodal and combined transport, IT in flow management, automation of processes in transport) have significantly influenced the development of supply chains. These changes have also strongly influenced the development of multi-functional seaports, clustered forms of their operation as well as the pro-market approach of the functional segment. It is mainly these factors that determine whether a given seaport is an important element of a global or regional supply chain system. And as a consequence, it affects the creation and development of land-sea transport corridors, the seaport of which becomes a key link at the interface of land and sea. Figure 2 presents a diagram of combining loads of many shippers transported under different supply chains. The diagram illustrates the key importance of seaports in transport systems, where the simultaneous operation of institutions and enterprises of the seaport functional segment allows to reduce the costs of cargo shipments thanks to the scale effect.

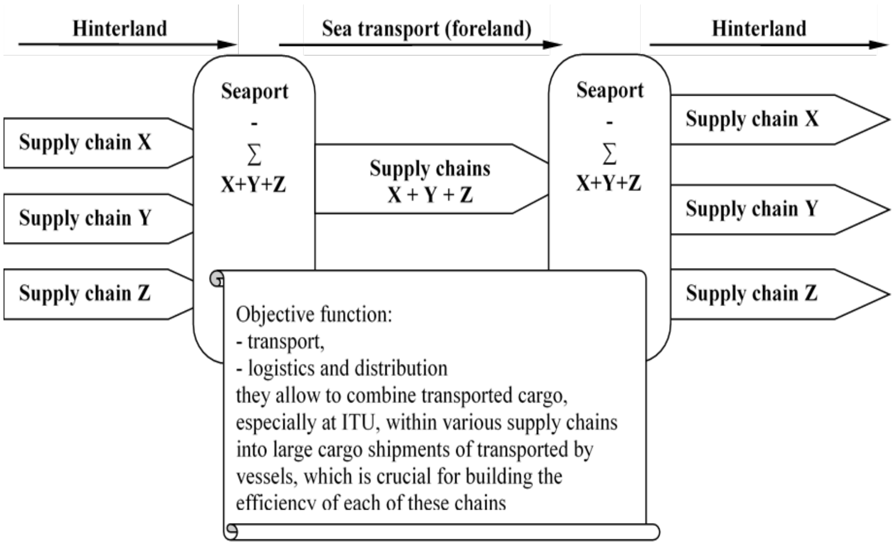

Figure 2 Diagram of connecting different supply chains by consolidating cargo in sea transport

Source: Own source

Due to the size of ships and the possibility of combining loads into larger batches, sea transport allows to lower unit costs of transport. Therefore, similar solutions have been sought for years in land transport. These solutions are part of the idea of transport corridors being both the subject of transport policy of states and regions, research analyzes as well as technical and organizational solutions implemented jointly by shippers and the sector of Transport Forwarding Logistics (TFL). An example are transport corridors in the EU TEN-T, where the European Commission and the Member States understand the network of key transport infrastructure for spatial integration of EU countries, sustainable development (environmental aspects) and its connection with other economies [13]. In the context of research analyzes, the Arnold study from 2006, under the aegis of WB[3], on best practices in managing international transport corridors [1] or the 2012 Notteboom publication on the strategy for the development of transport corridors in Europe [11] can be given as examples.

Studies and analyzes concerning transport corridors are an indication of past or future directions of infrastructure development as well as new organizational and technical solutions necessary to increase the

[3] World Bank

efficiency of land and sea transport chains for the TFL and shippers' sector. Nevertheless, in the case of loads, economic aspects are of key importance in the creation of transport corridors by shippers and the TFL sector.

As pointed in Arnold study [1], the transport corridor can have a global as well as a regional dimension. It can be a transport corridor, under which a number of different cargoes are transported, or ITU, but it can also be a corridor within which certain groups of cargo are transported within selected cargo categories. It may have one transport route layout, but it may also have a network layout in many transport paths between input and output nodes. It can be either one-legged or multi-branch in its land part. Multimodal and / or intermodal. In the national dimension, it can be part of a regional network. In the international dimension, as is shown by research and practice, in most cases the main seaport of entry or exit from the corridor is the seaport. This entry/exit system from the corridor is characteristic of Europe, where seaports and shipping are one of the key elements of the European transport system.

When analyzing transport corridors one should point to their functional aspects. Transport corridors are important for the economic development of regions by including them in the international system of communication of societies and the system of supply chains. They allow, through the local network, for social communication at the regional level and the distribution of goods within it. They also have a transit function that is particularly important for countries that do not have access to the sea or need a transport connection with distant regions for their development [1, 18].

5. EXAMPLES OF THE CREATION OF LAND-SEA TRANSPORT CORRIDORS BY EUROPEAN SEAPORTS

In the previously mentioned publication, Notteboom [11] presented several European transport corridors, the main entry / exit of which is seaports. These ports are multifunctional economic organisms of the III-V generation with developed objective and spatial functions (Figure 3), being both an element of the global and European system of supply chains, but also important socio-economic areas of the regions in which they operate.

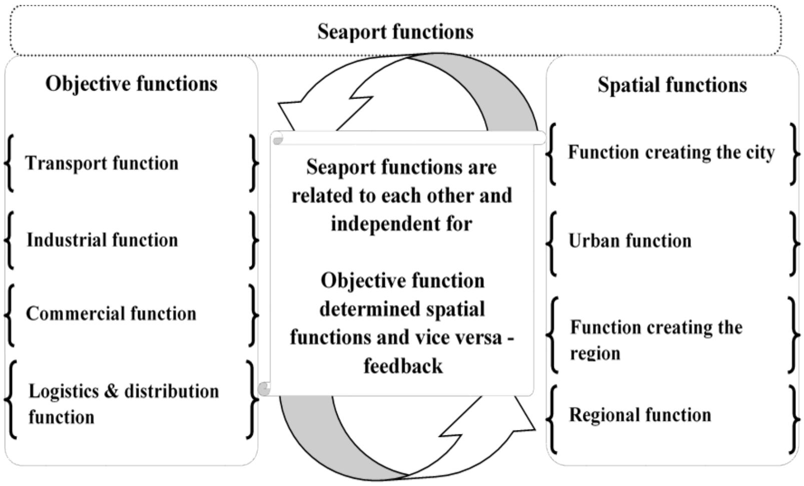

Figure 3 Seaport functions

Source: [9]

Managing the seaport is a system of administrative and management activities of a continuous nature, consistent with the adopted strategy, creating the conditions for the growth of economic activity satisfying the current and forecasted needs for its services and production in the socio-economic area of the seaport. A seaport can develop only in the case of a coherent strategy of the entire functional segment, including adjustments of regulators and the managing entity to create an operational and development sphere of development opportunities based on clear, long-term plans, which are understandable and accepted by the (internal and external) port environment.

Below, there are two examples of co-operation by maritime ports of transport corridors in Central, Eastern and Southern Europe. The author deliberately does not present the most known and widely analyzed transport corridors in Western Europe, where the stimulus for development are seaports, recognizing that the repetition of what is already widely described brings nothing new to the issue discussed.

Case study 1

Containerization, which allows the connection of loads of many shippers into channeled transport streams (Figure 2), has become the basic factor for the development of multifunctional seaports and the development of integrated logistics centers that are currently part of a global supply chain system. The seaports in Hamburg, Bremerhaven and Wilhelmshaven as well as the integrated logistics center GVZ Bremen are Europe's leading example of such development aimed at the dominant market segment. The mentioned seaports are characterized by a very high share of large containers in total transshipments. They operate in the largest German maritime container terminals. Currently, these three ports together with the port and the integrated logistics center (GVZ Bremen) in Bremen form the logistics platform H-W-B-B[4]. This is the platform with developed objective and spatial functions (Figure 3). Functions particularly important for these considerations include transport, logistics and distribution.

The ports in Hamburg and Bremerhaven have been specializing in container handling for almost 60 years. The container terminal in Wilhelmshaven, the youngest of them but the deepest one, supplements these three seaports in the implementation of the services expected by the market for containers, transported cargo and means of transport. The specialization of the H-W-B-B platform ports is demonstrated by the dynamics of container transshipment and their nearly 70% share in total turnover. In 2000, the ports in Hamburg and Bremerhaven handled nearly 7 million TEUs and in 2017, the three mentioned above, over 16 million TEU [21, 22, 23].

The transshipment of large quantities of cargo by seaports requires a developed access infrastructure both from the side of the foreground and back office. Without it, it is not possible to develop efficient and movable large loads of land and sea cargo transport chains. In the case of the H-W-B-B logistics platform, both the access infrastructure from the water side and from the land side allowed the development of such transport chains, which were transformed into transport corridors. The first one, developed since the 1980s, connects the ports of the logistics platform with the south of Germany and further with Northern Italy. The second one was formed at the turn of the 20th and 21st centuries and connects, both by land and sea (feeder shipping) platform ports with Central and Eastern Europe (Poland, the Czech Republic, Hungary, and Russia). The connection diagram of the H-W-B-B platform is presented in Figure 4.

[4] Hamburg-Wilhelmshaven-Bremerhaven-Bremen

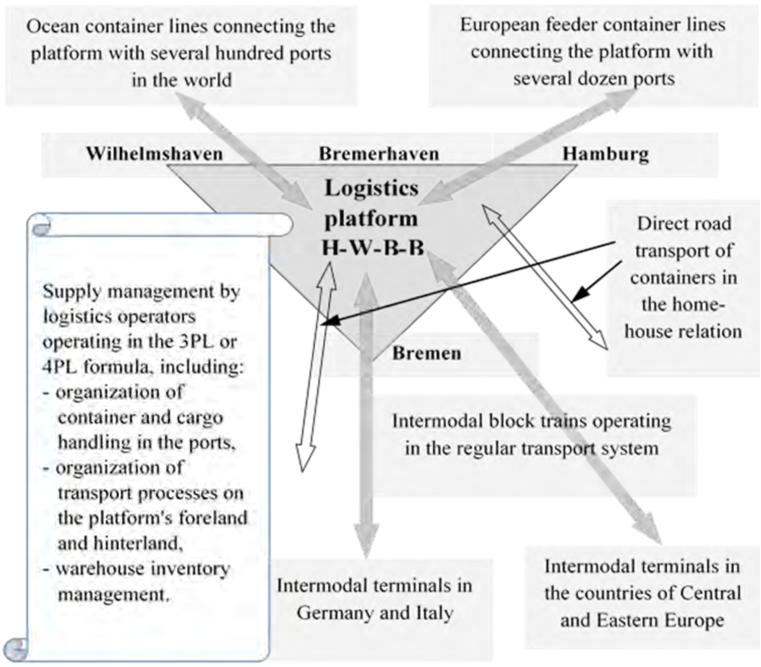

Figure 4 Connection diagram of the logistics platform Hamburg-Wilhelmshaven-Bremerhaven-Bremer with foreland and hinterland and an indication of the role of logistic operators

Source: [10]

Both transport corridors are characterized by a common entry (import) / exit (export), which are the ports in Hamburg, Bremerhaven, Bremen and Wilhelmshaven, taking the form of a network in their hinterland. Corresponding corridors with local supply networks are highway junctions with distribution centers (road transport) and intermodal transport terminals (rail transport) operating independently: as part of integrated logistics centers, inland ports or dry ports. These terminals are crucial for the efficiency of flows in corridors, as the product of transport are primarily large containers supplemented with other ITUs transported in a combined transport system. Due to the congestion, which is growing across Europe, the transport by ITU railways in both corridors is gradually increasing, which allows for timely delivery and, as a consequence, lowering the costs of storing goods in the supply processes. An example of the above approach to changing the structure of ITU transport in both transport corridors are transports between the ports of the H-W-B-B logistics platform and the "Bayernhafen Gruppe"[5]. The platform is based on six inland ports in Aschaffenburg, Bamberg, Nuremberg, Roth, Regensburg and Passau (four of them have intermodal terminals), where GVZ Nuremberg is key from the point of view of its economic activity. Between the two platforms, several dozen block container trains operate according to the timetable, with a total capacity of several thousand TEU per day [24].

The above example of transport concentration in the transport corridor illustrates many years of its trends in Europe - concentration of fixed and large loads on fixed routes between transport nodes using railway, inland or pipeline transport and dispersed transport using road transport. Therefore, it should be said that nothing will change in this matter in the coming years. What is characteristic of Europe is the change in the structure of transport carried out in transport corridors to increase long-haul transport by modes of transport other than road transport. In order to make this possible, a linear and nodal infrastructure is to be applied to transport cargo in a multi-branch system using multimodal, intermodal and combined transport techniques. The example of transport corridors described above, co-created by the functional segment of the H-W-B-B platform ports, is part of such transport corridors development in Europe.

[5] As part of a widely conducted research on the transformation of European transport hubs into logistics centers and logistics platforms, the author also analysed activities related to the development of one of them by accepting such a name for research purposes.

Case study 2

The second example presented is about stimulating the development of transport corridors through seaports in Gdańsk and Gdynia. Four milestones can be distinguished in their development after the Second World War. The first was the construction of an external port (the so-called Northern Port) in Gdansk in the 1970s that could accept the largest ships sailing in the Baltic Sea. In the newly created part of the port, a fuel terminal for handling crude oil was created. The second milestone was the construction the first in the Polish seaports of the container terminal in Gdynia, also in the 1970s. The third was Poland's and several other countries of Central and Eastern Europe access to the European Union and the fourth was the construction of Deepwater Container Terminal (DCT). Each of these milestones was a very strong developmental impulse, based on which the ports expanded both in the technical (infrastructure and superstructure, new terminals) as well as organizational and legal aspects (legal changes concerning the operation of ports, long-term development strategy of each of them, development functional segment towards a clustered operating system). The internal development was accompanied by the integration of ports in Gdańsk and Gdynia with the following areas: technical (access infrastructure both from the sea and land), legal (legal adjustment of the functional segment in relations with the environment to EU regulations) and organizational (close links between the functional segment of both ports TFL sector companies, shippers and the public sector). As a result, the seaports in Gdansk and Gdynia have become a multifunctional economic areas functioning as third generation ports. The level of development they have achieved allows these ports to stimulate the development of transport corridors in their hinterland.

Currently, seaports in Gdansk and Gdynia are nodes of entry and exit of the transport corridor, under which various loads are transported, including ITU. The corridor is network-linked, connecting both ports with Central and Eastern Europe. Depending on the load or ITU, transport chains being elements of the corridor are organized differently. The first example is the transport of crude oil and its products to and from both ports' hinterland. Fuel terminals operating in the port of Gdansk are connected with the oil pipeline system running from Russia to Germany. Thanks to the fact that the pipeline from Gdańsk to Płock (connection with Przyjaźń Pipeline) is a two-sided pipeline, for several decades the fuel terminals in Gdansk have reloaded crude oil either in export (Russian oil) or in import (supplying Polish oil refineries but also supplying refineries in Schwedt). An element of successively developed fuel transport chains are also railway and road transport of crude oil products (import and export) produced by refineries located in Gdańsk and Płock, and bought for the Central European market and transshipped by terminals of petroleum products in the port of Gdansk. The total transshipment of crude oil and its products exceeded 15 million tonnes in 2018 [25].

As previously indicated, one of the four milestones in the development of ports in Gdansk and Gdynia was the construction of DCT in the port of Gdansk, which is now included in the network of ocean container ports. As a result, both of these ports became a Baltic container hub with a total container reloading of 2.8 million tonnes in 2018 [25, 26]. The rapid increase in container handling in the last 10 years has contributed to the dynamic development of container transport chains in the Gdańsk / Gdynia - Central and Eastern Europe corridor. These transports are carried out in a similar way as in the whole of Europe. Container block trains to over a dozen intermodal terminals located in Poland, some of which also have railway connections in intermodal terminals in the countries of Central, Eastern and Southern Europe. Some of the containers are transported by road from container terminals located in both ports directly to cargo recipients located in the port hinterland. Some of the containers from DCT are delivered by feeder ships to small Baltic ports and, in turn, by other container feeder lines to container terminals in Gdynia. This indicates the multi-directional flows both in the foreland and hinterland of both ports (Figure 5).

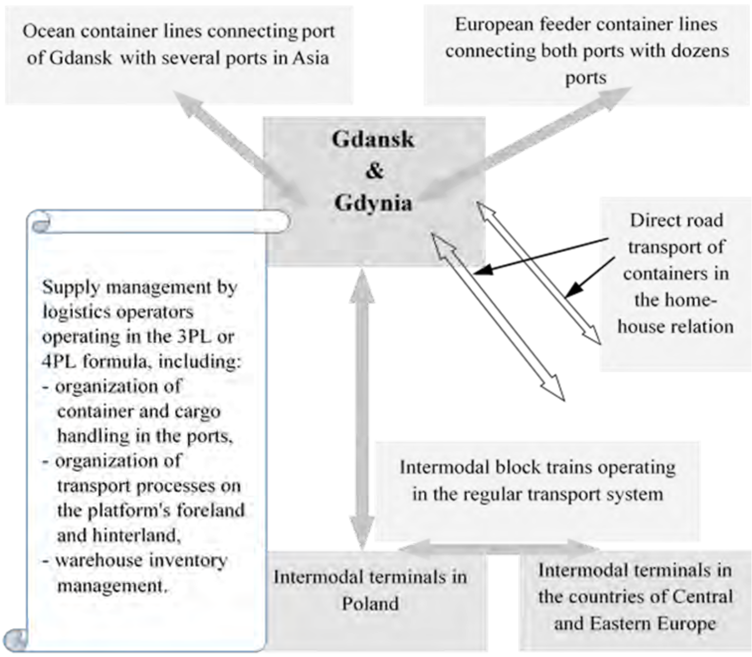

Figure 5 Diagram of container connections in Gdańsk and Gdynia ports with foreland and hinterland and indication of the role of logistic operators

Source: Own source

The third transport chain important for the development of the discussed corridor is the transport of loads in rolling units such as trucks and semitrailers. In this case, the ports in Gdansk and Gdynia are transit nodes between Scandinavia and Central and Southern Europe. The transport between Scandinavia and Poland and other countries of Central and Southern Europe is increasing year by year. Unfortunately, for the time being, long-distance transport via both ports is carried out by road, as none of the discussed ports has a technical infrastructure to handle ferry and ro-ro transport allowing for the formation of trains transporting semitrailers or trucks in a combined transport system with the use of rail transport as the main transport route in Poland and further in Central and Southern Europe. However, such transport, next to containerized transport already implemented, would fit into the idea of the Baltic-Adriatic transport corridor. A corridor recorded in EU documents linking countries of Scandinavia-Adriatic area.

It is no coincidence that the author chose sea ports in Gdańsk and Gdynia for the case study, pointing to their role in shaping the transport corridor Gdańsk/Gdynia-Central and Eastern Europe, referring above the idea of the Baltic-Adriatic multimodal transport corridor. Analyzing this case, the author wanted to draw attention to the long-term process that takes place in Europe, consisting in creating a network of transport corridors by connecting individual corridors into one system, where seaports are node entry, exit or transit elements. This is no different in the case of the Baltic-Adriatic corridor described in the EU TEN-T, where the seaports of the southern Baltic and northern Adriatic should be the stimulators of combining the various transport corridors that operate in the Baltic-Adriatic areas, not correlated with each other. According to the author, the functional segments of these port groups of both seas should be a natural stimulus for the creation of the Baltic-Adriatic network transport corridor, cooperating in this task with the public sector as well as shippers operating in the area between the two seas.

6. CONCLUSION

The global system of supply chains has become the basic factor shaping the global transport system, in which a key role is played by maritime transport. Thus, the significant role in this system is played by seaports, which gather cargo streams of many shippers in their space. The larger the range of port, forwarding and logistics services a given port implements, the more added value it creates in the process of handling loads, and it is more eagerly chosen by shippers and logistics operators to handle their cargoes in sea-land transport chains. Therefore, multi-purpose seaports of the III-V generation, with an expanded functional segment, are stimulators for the development of integrated transport corridors as their main entry / exit nodes. European practice provides a number of examples of transport corridors leading from and to seaports. Corridors that currently form a network of interconnected transport routes with transport nodes, combining local supply (distribution) systems with a global supply chain system, which they are a part of.

REFERENCES

[1] Arnold, J. (2006) *Best Practices in Management of International Trade Corridors*. Transport Papers TP-13. The International Bank for Reconstruction and Development/The World Bank Washington. http://documents.worldbank.org /curated/en/441171468315291413/pdf/384590Internat1e0corridors01PUBLIC1.pdf [10.07.2019]

[2] Christowa, Cz. (2011) *Systemy zarządzania i eksploatacji w polskich portach morskich (ze szczególnym uwzględnieniem portów w Szczecinie i Świnoujściu)*. Wydawnictwo Naukowe Akademii Morskiej, Szczecin

[3] Ducruet, C., Notteboom, T. E., de Langen, P. W. (2009) Revisiting Inter-Port Relationships under the New Economic Geography Research Frameework. In T. Nottenboom, C. Ducruet & P. De Langen (Eds.), *Port in Proximity Competition and Coordination among Adjacent Seaports* (pp. 11-27), Ashgate Farnham & Burlington

[4] Grzelakowski, A., Matczak, M. (2012) *Współczesne porty morskie. Funkcjonowanie i rozwój*. Wydawnictwo Akademii Morskiej w Gdyni. Gdynia

[5] Hlali, A., Hammami, S. (2017) *Seaport Concept and Services Characteristics: Theoretical Test*. The Open Transportation Journal. Vol. 11, pp. 120-129

[6] Lee, P. T. W., Lam, J. S. L., Lin, C. W., Hu, K. C., Cheong, I., (2018) *Developing the fifth generation port concept model: an empirical test*. The International Journal of Logistics Management, https://doi.org/10.1108/IJLM-10-2016-0239

[7] Lee, P. T. W. and Lam, J. S. L. 2015. Container Port Competition and Competitiveness Analysis: Asian Major Ports, In: Lee, C.Y. and Meng, Q. (eds.) *Handbook of Ocean Container Transport Logistics – Making Global Supply Chain Effective*. International Series in Operations Research & Management Science, Vol. 220, New York. Springer, pp. 97-136. DOI: 10.1007/978-3-319-11891-8_4

[8] Montwiłł, A. (2014) *The Role of Seaports as Logistics Centers in the Modelling of the Sustainable System for Distribution of Goods in Urban Areas*, Procedia Social and Behavioral Sciences, Vol. 151, pp. 257-265

[9] Montwiłł, A. (2016) *The impact of the development of seaport objective functions for a cargo logistics system in urban areas, illustrated with an example of the Szczecin Metropolis*. Transportation Research Procedia No. 16. pp. 366 – 377

[10] Montwiłł, A. (2016) *Analiza znaczenia portów morskich i zintegrowanych centrów logistycznych w zarządzaniu procesami w transporcie intermodalnym i kombinowanym w Europie na wybranym przykładzie*. ZN US „Problemy Transportu i Logistyki". Vol 34, pp. 144-154

[11] Notteboom, T. (2012) *Strategies and future development of transport corridors*. https://www.faq-logistique.com/EMS-Livre-Corridors-Transport-18-Strategies-Future-Develoment.htm [10.07.2019]

[12] Sołtysik, E. (2009) Rozwój koncepcji logistyki, In Kisperska-Moroń, D. & Krzyżaniak, S. (Eds) *Logistyka*. Biblioteka Logistyczna. Poznań pp. 11-30

[13] European Commission (2014) Ports 2030 Gateway for the Trans European Transport Network https://ec.europa.eu/ transport/sites/transport/files/modes/maritime/ports/doc/2014-04-29-brochure-ports.pdf [12.06.2019]

[14] Regulation (EU) 2017/352 of the European Parliament and of the Council

[15] UNCTAD (1999) *The fourth generation port*, UNCTAD Port newsletter, Vol. 19, pp. 9-12

[16] UNCTAD (1991) *Port marketing and the challenge of the third generation port*. UNCTAD TD/B/C.4/AC.7/14, Geneva 1991 https://unctad.org/en/PublicationsLibrary/tdc4ac7_d14_en.pdf

[17] United Nations. Economic and Social Commission for Asia and the Pacific (2002) Commercial development of regional ports as logistics centres. New York

[18] https://ebrary.net/17180/business_finance/transportation_corridors [10.07.2019]

[19] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Maritime_ports_freight_and_passenger_ statistics [12.06.2019]

[20] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Gross_weight_of_seaborne_goods_ handled_in_main_ports_by_type_of_cargo,_EU-28_2018Q3.png [12.06.2019]

[21] https://www.hafen-hamburg.de/en/statistics, [12.07.2019]

[22] http://www.bremenports.de/en/statistics, [12.07.2019]

[23] http://www1.eurogate.de/en/Terminals/Wilhelmshaven [12.07.2019]

[24] https://www.bayernhafen.com/services/intermodal/ [12.07.2019]

[25] http://www.portgdansk.pl/o-porcie/statystyki-przeladunkow [14.07.2019]

[26] https://www.port.gdynia.pl/pl/port/statystyki [14.07.2019]

THE METHODS OF ACQUISITION AND EXTRACTION OF SMALL AMPLITUDE SIGNAL RADAR ECHOES

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Summary

Development of electronics and computer sciences has brought the following-on, new conceptions in using radar for navigation purpose. Applying digital technologies enabled different approach to a question of processing and analyzing radar displays. The paper describes research on usage of radar information for the sake of navigation safety. Introducing the new technologies and also the software, capable to analyze visual radar signal, may considerably perfect the echoes detection process, increasing thereby a probability of detecting usable echoes, including those, occurring within the interference area.

Keywords: radar, detection, radar signal, image processing

1. INTRODUCTION

The navigation process, supported by automated anti-collision systems ARPA has been up till now of a relatively low accuracy. Reasons thereof were not only the difficult to eliminate radio waves disturbances (at the radar operation frequency) and technical limits in radar echo presentation, but also the mistaken identification of radar echo, random and deterministic radar observation interferences and a lack of time synchronization (or of simultaneity) in the process of acquisition of radar information about objects' location. The ARPA equipment, nevertheless continuously improved, has not been perfect. Its imperfection is low noise immunity, including the passive one, also a low sensitivity, impeding detection of small objects, sometimes even making it quite impossible. Bearing the above in mind, one can state, that there is a necessity of carrying out the research works, focused on further development of the mentioned equipment. Introducing the new technologies and also the software, capable to analyze visual radar signal, may considerably perfect the echoes detection process, increasing thereby a probability of detecting usable echoes, including those, occurring within the interference area.

2. VISUAL RADAR SIGNAL

The most often ships' navigational radars are of incoherent type, operating on the basis of the pulse principle. There the most often a slot or micro -strip antennas are used. A type of the antenna and its parameters are of essential influence on detection capability of any radar. The extremely important parameters are dimensions of characteristics of radiation in horizontal plane Θ and in vertical plane ε as well as the antenna gain *G*. The radar antenna is an antenna, which turns around its axis at a speed of a range between 24 and 30 rotations per minute (r. p. m.). An accuracy of the angle measurement and a number of pulses in a "target pack" ηi depend on a width of the horizontal characteristics and antenna's rotational speed.

The antenna operation is to radiate into space a scanning signal, which, after hitting any object, gets partly dispersed, partly reflected off the object and directed back to the antenna, wherefrom, through switch, it is transmitted toward the receiver. At the receiving path income there is a low-noise microwave amplifier. After the signal is amplified with the amplifier, it is transmitted to the mixer, where transformation of the signal's frequency to the intermediate frequency $f_{i.f}$ takes place. Then the signal is amplified in the intermediate frequency amplifier and is subject to detection in the detector system, wherefrom in a form of visual impulses is transmitted to the visual amplifier.

The amplified visual signal is transmitted to the false alarm level stabilizing system (Constant False Alarm Rate – CFAR), where a decision on detection of the object is undertaken. In case the decision about detecting the target is taken, the signal is transferred to the vision receiver, where the analogy signal is converted to its digital form, recorded in the RAM memory. The synchronizing pulses, signals informing on the antenna position's angle and signals from such cooperative equipment as keyboard, gyrocompass, log and navigational receiver are delivered to RAM as well. The RAM [memory] block works in two-port operation mode, to enable simultaneous recording of the primary vision and its read-out through a graphics controller.

A basic task of the graphics controller is a proper arrangement of display on the indicator's screen.

2.1. Characteristics of Objects' Radiation

Depending on electromagnetic wave reflection manner, the objects can be divided into: singular objects (made from a homogeneous material), group objects (composed of several singular objects lying within a beam of scanning pulses) and spread out objects of a continuous nature (embracing a large area or volume - sea, land, clouds area, also a precipitation area).

Larger are dimensions of the object, if compared to a length of scanning pulses carrier wave, higher electromagnetic wave's energy it reflects. Thus the object's effective reflection area is bigger.

When the object's dimensions are smaller than the wave length, then diffraction of the carrier wave occurs instead of reflection, and the object is not radar detected. However the objects, having at least one of sides of a dimension equal to a half or multiplicity of the wave length, cause resonance reflection of relatively high intensity. In analytic calculations the mean value of the effective reflection area is assumed, whereas the true value, which often differs from the mean value, is defined with a use of characteristics of the object's radiation in horizontal plane. It depends on the following:

- object's dimensions, as a matter of fact, an area of its projection on a direction orthogonal to the scanning pulse,
- object's shape,
- object's position,
- radar's operation frequency,
- type of material.

2.2. Sea Surface Echoes

A radiolocation antenna located at ha height of directional characteristics with its width in horizontal plane Θ and in vertical plane ε is to light up sea surface at a distance r at an angle of γ. A surface element ΔS, differentiable on the radar screen, is of sizes resulting from distributive parameters. As the angle of electromagnetic wave incidence is acute, the elementary surface ΔS can be computed using the formula [2]:

$$\Delta S = \frac{c\tau\, \Theta\, r}{2} \tag{1}$$

The effective reflection area σ_s of the elementary surface ΔS is calculated applying the formula [2]:

$$\sigma_s = \sigma_{os}\Delta S = \frac{\Theta\, c\tau\, \sigma_{os} r}{2} \tag{2}$$

where:

σ_{os} – unit reflecting surface of the superficially spread out object

The unit area reflecting off sea surface σ_{os} is determined experimentally. Its size is affected by the electromagnetic wave frequency and polarization, radar beam's slope angle γ and sea state.

Observations of sea surface echoes' signals have proved that their structure is near to noise, produced in radar's receiving system. The reflections are visible around the time base point, to a distance, depending on state of sea and radar's parameters, making difficult, often impossible, to detect any other useful objects' echoes within this area. In effect of degradation of the signal/noise relation, radar usability for navigation or anti-collision purpose becomes limited.

A level of the signal reflected off sea surface may be expressed with a use of the following formula [5]:

$$P_m = \frac{P_i G^2 \lambda^2 \sigma_{os} \Theta\, c\tau}{2(4\pi)^3 r^3} \cdot F^4 \tag{3}$$

where:

P_m – level of singular sea surface echo [W],

F – interference factor.

2.3. Structure of Visual Radar Signal

The broad-band intermediate frequency amplifier in navigational radars is a logarithmic amplifier, producing a video signal of +1,75V amplitude in the reception line (Downlink). Selection of the reception band width is connected with a scanning pulse length.

The structure and the exemplary visual signals are presented in Figure 1 to 3. Depending on the applied measurement point the visual signals may be of positive or negative polarization.

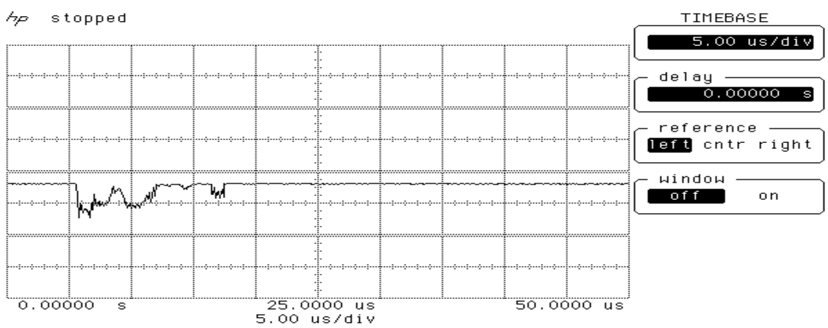


Figure 1 Visual Signal at Low Amplification Level

The time course of 5 μs/scale interval represents a distance of 750 m/scale.

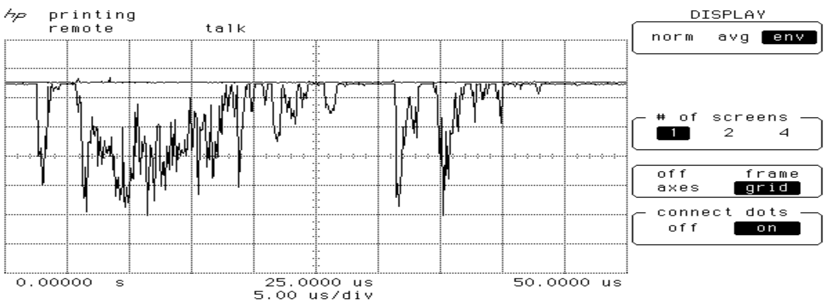


Figure 2 Visual signal at Normal Amplification Level

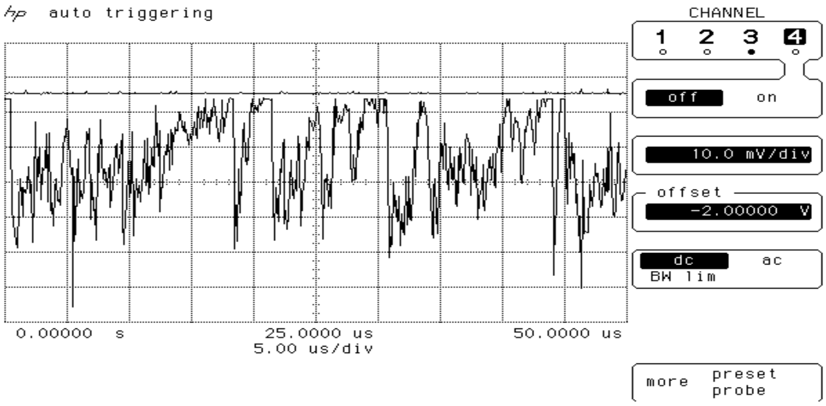


Figure 3 Visual signals of echoes coming from land

Visual signal processing systems and conversion of analogy signal to its digital form are performed through video processors VPA and VPB. The both processors, together with the other systems, form so-called RPU (Radar Processor Unit).

RSC controller (Radar Scan Converter) is responsible for recording the visual signal in RVM memory (radar video memory) applying rectangular X-Y coordinates, creating thereby an individual address for each cell of the signal. The radar signal is saved in the memory at three following levels: low, medium and high. If it appears in an individual pixel for the first time, it is saved at the low level, if it appears again at the next rotation of the antenna, then it is saved at the medium level and on the screen there appears a point of an average brightness. When the signal appears for the third time, it achieves the maximal brightness level. It allows reducing brightness of signals reflected off sea surface.

2.4. Problems of Detecting Small Signal Amplitude Echoes

The problem of radiolocation used for detection of vessels at sea is essential to enable the broadly understood safety of navigation; its importance is even higher in searching and detection of objects upon salvage and sea rescues actions.

Searching watercraft objects is often carried out in extremely sever meteorological conditions. State of sea, lacking in visibility or its serious constraints become a reason that vessels radiolocation equipment stands for the only source of information about objects in search area. An appropriate training of crews and their knowledge about phenomena occurring in detection process enable to use the vessels radars effectively. It is also a significant issue to carry out research over possibilities in detection of radar echoes, coming from small objects or objects of small reflection area, unnoticeable within the background full of noise and disturbances.

On one hand the research should refer to problems in electrotechnics and concern on propagation and reflection of electromagnetic waves and on creation of theoretical fluctuation models of vessels (see [1]), on the other hand they should focus on seeking new concepts in improvement of radar display visualization through additional working out and digital processing of visual signal, increasing thereby probability of detecting the weak signal echo. The assignment should consist in seeking such features of radar echo's visual signal, which may distinguish it from noise and interferences/disturbances. It can be a value of radar echo signal voltage, shape of the signal (radar echo signal), frequency of its occurrence or the radar echo state vector parameters, defined in a result of the research. [6], [7], [8].

In the both subjects to investigate, an influence of sea environment and disturbances caused by sea surface should be taken into consideration.

In a peculiar way the above issues affect propagation of electromagnetic waves and dynamics of changes of water surface objects' radiation on theoretic fluctuation models [5]. Classification of the object to respective fluctuation model depends, among the others, on a type of statistic distribution of the measured values of the effective reflection area in relation to the object's orientation angle. The main statistic distributions applied in modelling objects are Rayleigh's and χ^2 distributions.

At present a great number of vessels are made – as a whole or in a large part – of various types of plastics, seriously deteriorating potentialities of detecting them by radiolocation equipment. A quality of detecting such objects depends mainly from the installed radar reflectors' quality.

Passive radar reflectors, installed on small vessels, are practically the only equipment capable to reflect electromagnetic wave, radiated by radar antenna and reaching the vessel. Thus, operation of these devices is decisive for a shape of the vessel's radiation characteristics and a size of its effective reflection area.

While searching for new fluctuation models, there have been carried out studies on radar reflectors, which enable to define potentialities of detecting small vessels using radiolocation. They also may be used to construct new systems of echo detection. [6], [7], [8].

3. DETECTION OF WEAK RADAR ECHOES

The methods for detecting weak radar echoes in a visual radar signal will be presented below. These methods have been tested on real signals by the authors of the paper. They are based on the use of the characteristic features of a radar visual signal representing a radar echo with a low signal threshold. Some of the methods cited are innovative. One can also include methods based on artificial intelligence and an estimation method used in geodesy for the development of measurement data. This has been described, among others, in [3], [4], [6], [7], [8].

3.1. Detection of Weak Radar Echoes Using the Signals Summation Method

Visual signal coming from a superficial object should be characterized with a constant position in relation to the radar antenna location (having assumed that the object is not in motion or moves slowly, and successive signal recordings were carried out at every antenna's rotation). Noise and disturbances are of random character. A quality of detecting the above mentioned objects against the random disturbances background can be improved applying the method of summation of the images doming from the same position, also making an assumption that the observed objects were motionless or they move inconsiderably.

One of the basic techniques applied to remove the random disturbances is summation of many images of the same object. Assuming that a certain accidental defect is found in every image, then when they are added up there is obtained the object image containing disturbances from all the compound images. Anyhow, a level of these undesired signals, in relation to the usable signal, is much lower than it is originally. Increasing a number of the images added would cause further growing a difference between the desired signal and disturbance.

The presented process of summing images consist in adding values of courses of all the visual signals, conforming to each other, coming from one position. Afterwards the normalization aimed at scaling of the signal level to the admissible values interval is carried out. The summation result is presented below.

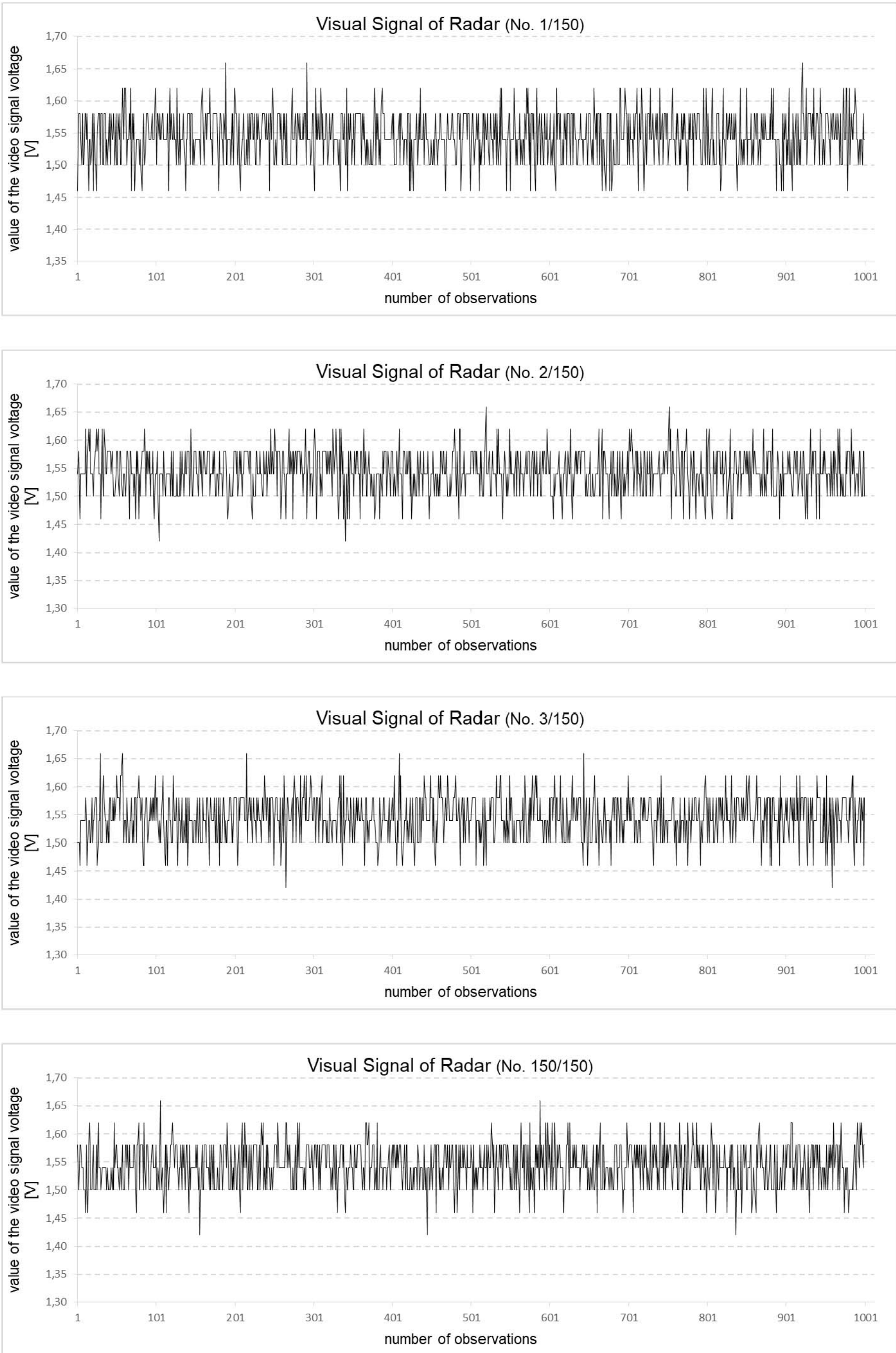


Figure 4 The Real Visual Radar Signals (4 from 150 exemplary courses)

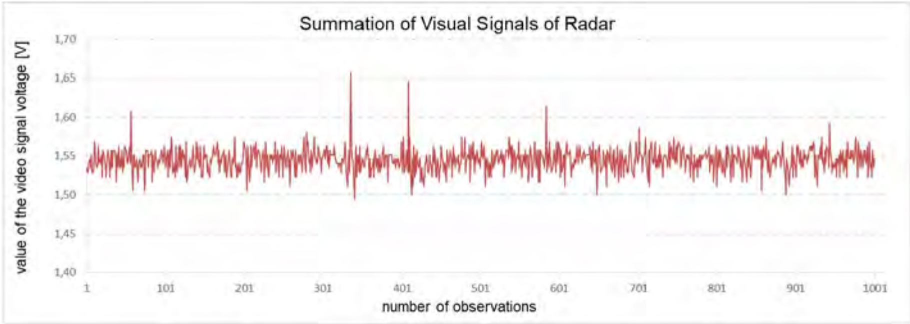


Figure 5 Summation of Visual Signals (observation of constant objects of low signal level)

The method results prove satisfactory for the successive visual signals recorded on the constant azimuth. The Figure above (Figure 4) shows 4 exemplary courses of the recorded visual signal. In Figure 5 there is displayed a result of summation and normalization of visual signals values for 150 courses. It corresponds to about 7, 5 minutes of recording time. The extracted values of the visual signal voltages values corresponding to probable echoes reflected from the objects, which had not been detected earlier are clearly visible.

In Figure 5 one may notice a growth of the signal voltage mean values already on summation of three successive courses thereof. The other part of the signal was effectively weakened. In the above presented example 4 characteristic radar echoes were detected. The method is characterized with simplicity of realization and high operation rate. It requires however holding the radar antenna position unchanged while the measurement data are acquired.

3.2. Detection of Weak Radar Echoes Applying the Gradient Method

In the following method it was assumed that the hard to detect radar echoes are characterized with not only a low signal level but also its shape. The signal is obviously at the noise level; anyhow it is slightly "wider" than them. One expects that some sampled values of signal voltage occurring one after another are at a similar level.

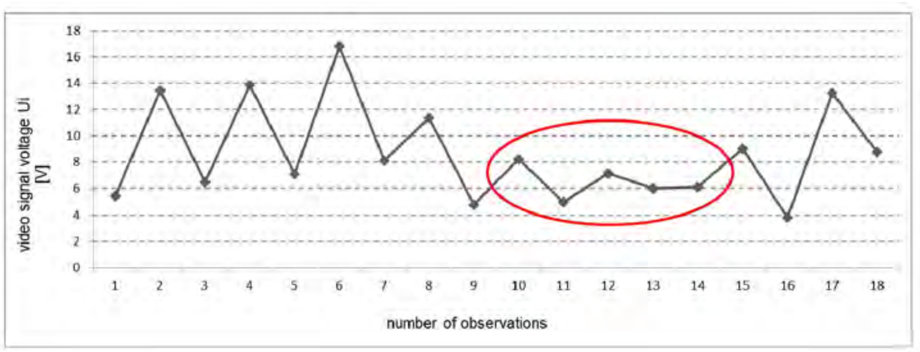


Figure 6 Weak Radar Echo of Characteristic Shape

The method operation is based on dividing the signal voltage value by a slope gradient sum or a growth of adjacent signal voltage values. The method is operating in conformity with the dependence:

$$U_j = \frac{U_i}{|gradU_{i-1}| + |gradU_{i+1}|} \tag{4}$$

where:

$gradU_{i-1}$ - gradient of voltage value changing between U_i and U_{i-1}

$gradU_{i+1}$ - gradient of voltage value changing between U_i and U_{i+1}

In result of dependence formula no. 4, the new visual signal is obtained; it is presented below.

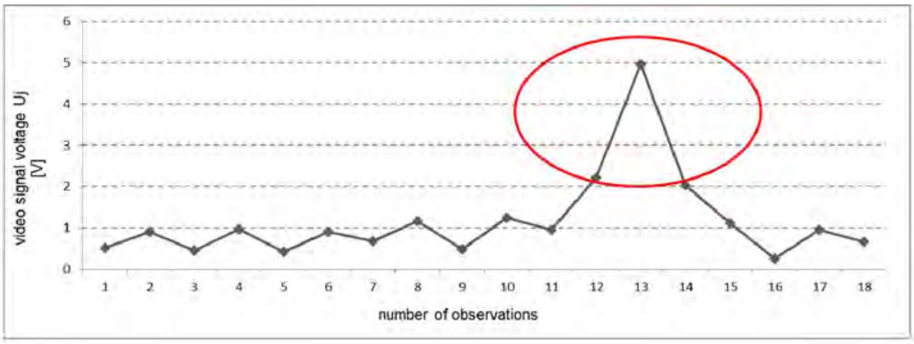
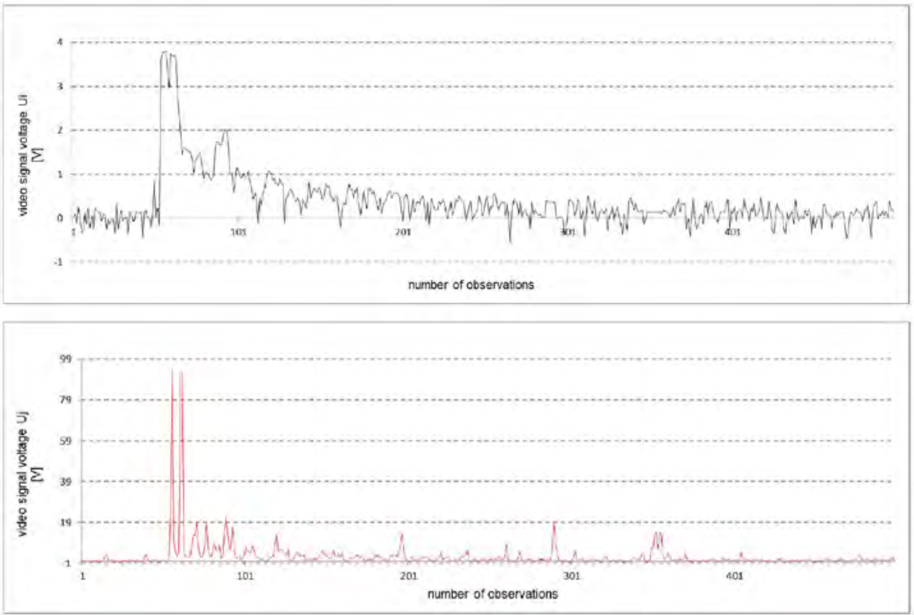


Figure 7 Detection of Weak Radar Echo Applying the Gradient Method

Effects of the method were tested applying the real radar visual signals and the obtained results were satisfactory. The method operates very fast and enables to detect weak radar echoes in true time.



4. CONCLUSION

Application of radars on sea-going ships and vessels is essential for safety of navigation, especially in poor visibility and bad weather conditions. Radars are used in navigation for fixing positions and for detection and identification of vessels, objects and other targets. A process of carrying out navigation basing on automated anti-collision systems ARPA is till now characterized with comparatively low accuracy. The reasons thereof are not only, difficult to eliminate, radio waves interferences and technical constraints in presentation of radar echo on the screen, but also misidentification of radar echo, as well as random and deterministic disturbances of radar observations.

Radar echoes may come from vessels and targets, characterized with lowered qualities of microwaves reflection, as, for example, objects constructed applying stealth technology.

Radar is basic equipment used by a navigator in navigation at sea to avoid collisions with other objects, present in water area. The contemporary radar techniques reached at the moment a level, allowing construction of high sensitivity modern radars, capable to detect large size and extensive reflection area objects and, what is also important, any small size objects, generating weak radar echoes. However, in case of such equipment, a serious problem is discrimination of true radar echo and a noise, appearing in a signal, received from the antenna. In case of minor objects, generating weak echo, a level of signal is very often at the same level as the said noise. Weak echoes of navigational radars, contemporary in use, are eliminated from radar display due to hard differentiability from noise. Anything what is below the assumed threshold is removed. The only criterion applied in forming the radar image, using a signal received from the antenna, is a level of such signal. Its other parameters, as its shape, for example, are not taken into consideration. A consequence of that method of radar image production is such an issue, that minor objects, as yachts, are often invisible for a navigator (not displayed in radar image) what was a reason for many collisions at sea.

It seems that to increase detectability of the objects for which it is characteristic that their radar signal's level is low, and to be able to make such information available for a navigator having in mind navigation safety, formation of radar image from a signal from the antenna should include its shape, not only the signal level. The system, analyzing the radar signal, should be capable to search in the signal any of the points which are characteristic for true echoes, differentiating them thereby from other contents.

Application of the digital signal's filtration methods may provide navigators with information about the objects which remain invisible on the contemporary radars' indicators. It does happen, as their echo is at a level (or below) of noise and interferences occurring within the radar presentation. When the original visual signal is examined in navigational radar's receiving block and the advanced technology used to produce multi-dimensional visualization, the radar image can be presented applying representation, increasing probability of detecting those objects. Apart from the fact, that in IMO Regulations the requirements referring to radar indicators and detecting capabilities of deck radiolocation equipment are explicitly defined; it is purposeful to search for new solutions in this subject, having in mind increasing safety of navigation.

REFERENCES

[1] Kilgard M. J., The OpenGL Utility Toolkit Programming Interface API, Version 3.0, Silicon Graphics, Inc. 1996.

[2] Nathanson F. E., Reilly J. P., Cohen M. N., Radar design principles: signal processing and the environment, Technology & Engineering, USA 1999

[3] Praczyk T., Adaptation of r-contiguous-bits scheme borrowed from immune systems to characteristic points of radar image identification, Theoretical and Applied Informatics, vol. 19 (2007), pp. 37-56, 2007

[4] Praczyk T., Using real valued detectors in ship immune system, Computing and Informatics, Vol. 29, 975-987, 2010.

[5] Szklarski A., Radiolocation detection of passive radar reflectors on small floating vessels, doctoral dissertation, Faculty of Electrical Engineering, Maritime University of Gdynia, Gdynia 2009.

[6] Wąż M. Rejestracja i przetwarzanie zobrazowania radarowego w celu zwiększenia możliwości detekcji ech o niskim poziomie sygnału (ang.: Registration and processing of radar imaging to increase the ability to detect low-level echoes), Logistyka nr 6/2011, Politechnika Radomska; pp. 3887-3894.

[7] Wąż M., Naus K.: Wykrywanie ech radarowych o małej amplitudzie sygnału (ang: Detection of radar echos with low signal amplitude) Logistyka nr 3/2012, ISSN 1231-5478, Politechnika Radomska; pp. 2397-2400,

[8] Wąż M., Stupak T.: Amplitude detection of weak radar signal. Barcelona 5th The International Congress on Maritime Technological Innovations and Research Barcelona, November 23, 2007, Technological Innovations and Research Barcelona Equipment, Services & Maintenance pp. 677-682,

COMFORTABLE ELECTRICAL YACHTS WITH SPECIAL SHAPED UNDERWATER HULLS

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Summary

The SWATH technology improves the seekeeping characteristics of ships due to the use of underwater hulls. To reduce the energetic needs of such vehicles and pollution the special unseparated hull shapes can be used. Wind tunnel tests revealed the absence of separation on proposed bodies of revolution at large Reynolds number range. These facts open wide prospects for the use of unseparated shapes in order to improve the commercial effectiveness of vehicles. For example, for a SWATH yacht the weight-to-drag ratio can be estimated approximately 165 and is 3 times higher than the estimation of lift-to-drag ratio for Solar Impulse 2 plane. Thus, such yacht can use electrical engines only and reduce the pollution. It is also possible to use solar sells to charge the batteries for the same yacht.

Keywords: environment protection, drag reduction, commercial efficiency, unseparated shapes, SWATH vehicles

1. INTRODUCTION

The urgent task of reducing the negative impact on the environment requires economical vehicles with minimal emissions of carbon dioxide and toxic substances. The clean-up of air air pollution from shipping is certainly needed. Many ships burn dirty fuels, such as heavy fuel oil, that contain high levels of sulphur and pollute the air with sulphur dioxide, particulates and black carbon. In particular, in was estimated in [1] that up to 40 per cent of the air pollution in coastal towns around the Mediterranean Sea can come from shipping. A report of French environment ministry concludes that particulate pollution from shipping causes 6000 premature deaths around the Mediterranean each year [1].

Croatian tourism is continuously growing (in 2012, there were nearly 12 million visits). Each year protected areas (e.g. national parks, the Plitvice Lakes, Krka, and Kornati) attract more visitors. Cruising and nautical tourism are the fastest-growing types of tourism and require efforts for adequate management of the marine environment, [2].

In the next few decades ships need to stop using fossil fuels altogether, as shipping is a major contributor to global warming [1]. Gradually all modes of transportation are being converted to electric propulsion and that includes maritime transport. Electric ships are already in operation in Norway and China

[3, 4]. Recreation yachts and ferries are a perfect place to start since they often travel only short distances and stay for relatively long periods of time at the same ports, where they can be charged. These ships can use the battery packs, which helps maintain a high charge rate while reducing peak demand costs [3,4].

The delay in electrification of the maritime transport (in comparison with automobiles or railways) is probably connected with the higher drag in water due to its much higher density. To overcome this drag much more powerful engines are necessary. Thus the problem of drag reduction is very important for maritime transport at all and especially for its electrification. Low drag of vehicles allows increasing their commercial efficiency [5] and range with the use of one charge.

To have all-season ships, their seakeeping characteristics must be improved. In particular, SWATH (Small Waterplane Area Twin Hull) technology use underwater hulls and allow the vehicle to move smoothly at rather high waves [6]. Improving the shape of these underwater enables to have a comfortable low drag yacht with electrical or even solar propulsion.

Vehicles or animals, which ensure a laminar attached flow pattern are expected to be the most effective, since separation and turbulence cause intensive vortexes in the flow, increase of drag and noise. The high swimming velocities of some aquatic animals such as dolphins continue to cause great interest of researchers. Testing the rigid bodies, similar to the animal shapes at close to real values of the Reynolds number (approximately six million), [7], and gliding dolphins (during the inertial movement without maneuverings and shape changes), [8], was carried out in order to explain the fact of the low drag by a very good shape only. From the point of view of these researches, the body shapes of good swimmers ensure the attached flow patterns. It is unclear, which methods were used in [8] to prove the absence of the boundary layer separation on the rigid animal like models. In [8] the bioluminescence was used to visualize the flow around the real gliding dolphins in natural conditions.

On the other hand, it is a commonly adopted practice to aim the static pressure minimum to coincide with the maximum of the body radius which leads to a positive pressure gradient and a separation downstream of this point, [9, 10]. Nevertheless, there are no theorems that restrict a body to have negative pressure gradients both up- and downstream of the maximum thickness point. Moreover, some examples of axisymmetric shapes with pressure decreasing near the tail have been calculated with the use of both the ideal and the viscous fluid approaches (e.g., [11, 12]); and manufactured and tested in wind tunnels [13, 14]. Unfortunately, a pressure decrease near the body tail is not enough to remove separation. For example, the flow separated on Goldschmied's body [13]; the separation was removed only with the use of boundary layer suction. A short survey of the theoretical and experimental results concerning these special shaped bodies of revolution are presented in Section 4 of this paper.

2. ESTIMATIONS OF COMMERCIAL EFFICIENCY FOR SWATH VEHICLE

The commercial efficiency of vehicles can be estimated with the use of drag-to-weight ratio $1/k$. The minimal value of this parameter yields the maximum of tons$\times$kilometers which can be transported by the vehicle per unit of time, [5]. With the fixed fuel (or another energy) capacity on its board, a vehicle with the maximum value of k has the maximum range. The drag-to-weight ratio can also be treated as the cost of motion, i.e. how much energy is used to move 1N of weight to the distance of 1m. Usually in literature, this characteristic is related to the 1 kg of mass or weight - $Jkg^{-1}m^{-1}$ (see e.g., [15]). By dividing the values in $Jkg^{-1}m^{-1}$ by 9.8 (the value of gravity acceleration *g*), we obtain the dimensionless criterion, coinciding with $1/k$.

The mass *m* of a SWATH yacht is related to the volume of an underwater hull *V* by simple formula $m \approx 2\rho V$, where ρ is the water density. Taking into account that the total drag of such vehicle is approximately twice higher than the drag *X* of each underwater hull and the volumetric drag coefficient $C_V = 2X/(\rho U^2 V^{2/3})$, we can obtain the formula

$$\frac{1}{k} = \frac{C_V \rho U^2 V^{2/3}}{mg} = 0.5 C_V Fr_V^2 \tag{1}$$

where the volumetric Froude number is related to the standard one $Fr_L = U/\sqrt{gL}$ (based on the vehicle length *L* and speed *U*) by the equation:

$$Fr_V^2 = \frac{U^2}{gV^{1/3}} = \frac{Fr_L{}^2 L}{V^{1/3}} \tag{2}$$

3. WAVE DRAG AND CRITICAL FROUDE NUMBER

The neutral buoyant vehicles are efficient at small Froude number only. The estimation of the critical value of the Froude number (based on the hull length) can be found in [16]. In particular, for a hull with a laminar attached boundary layer:

$$Fr^*_{L,lam} = 13.6 k_W^{-1/2}$$

where k_W (the aerodynamic efficiency for airplanes or planning ships). Usually, k_W cannot exceed the value 60 (and is much smaller for planning boats). Thus, we can use the estimation

$$Fr^*_{L,lam} \approx 2 \tag{3}$$

At smaller values of the Froude number, the commercial efficiency of the neutral buoyant vehicles (in particular, SWATH yachts) is higher than for vehicles with dynamical weight support (like high speed planning boats).

Estimation (3) exceeds another critical Froude number $Fr_L^* \approx 0.4$ which corresponds to the drastic increase of the wave drag on floating ships at supercritical Froude numbers. SWATH technology uses underwater hulls, therefore this increase can be neglected and faster yachts can be efficient in comparison with the standard floating boats.

4. SPECIAL SHAPED UNDERWATER HULLS

In the case of the attached flow pattern, slender bodies of revolution ensure low pressure drag and can delay laminar-turbulent transitions on their surfaces, [16, 17]. Therefore the reduce the skin-friction drag and total drag can be reduced on such bodies. That is why the unseparated rigid bodies cause great interest of researchers. During last 20 years the possibility of achieving a laminar attached flow on a rigid body has been investigated in the Institute of Hydromechanics (IHM) of National Academy of Sciences , Kyiv, Ukraine. The survey of these theoretical and experimental studies is presented in [14]. In particular, a shape UA-2c, similar to the dolphin body was calculated (see Fig. 1).

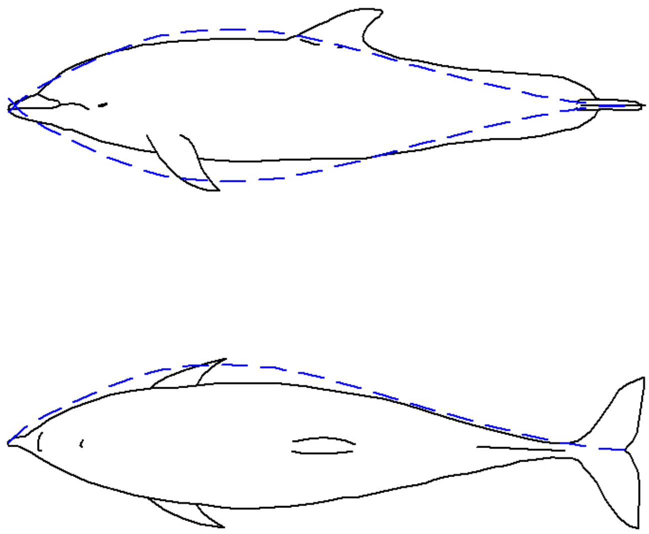

Figure 1 Comparison of the shape UA-2c with the body of a bottlenose dolphin, [18].

To fix the model on the wind tunnel, a support tube is necessary. It's presence was also simulated in [10]. A result of the calculations – unclosed shape UA-2 –was tested in IHM and later in the Institut für Strömungsmechanik (ISM) at Technische Universität Braunschweig, Germany, [19]. A good agreement between theoretical and experimental pressure distributions was obtained (see [19]), no visible separation and turbulence zones (e.g., the reversed flows) were revealed on body UA-2. These facts allow concluding that unseparated flow pattern occurs on the body of revolution UA-2. In comparison, separation occurred on Goldschmied's body and was removed only with the use of boundary-layer suction, see [13].

The method of calculation of shapes UA-2 and UA-2c was applied to obtain other bodies of revolution (with different thickness ratios *D/L* and positions of the maximum thickness point) and 2D profiles as well, see [14, 18]. The examples are shown in Fig. 2. The separation behavior of these shapes needs further experimental investigation. But their similarity with the bodies of aquatic animals allows expecting the attached boundary layer, as was shown in the experiments with the rigid copies of different fishes, [7]. Both the forebody and the tail of the shape corresponding to the smallest thickness ratio D/L =0.1, are concave, while for less slender bodies (D/L =0.21 and D/L =0.3) only the tail is concave (see Fig. 2). Some fast-swimming fish have a concave forebody too (e.g., the Mediterranean spearfish, Indo-Pacific sailfish, Black marlin, or Swordfish).

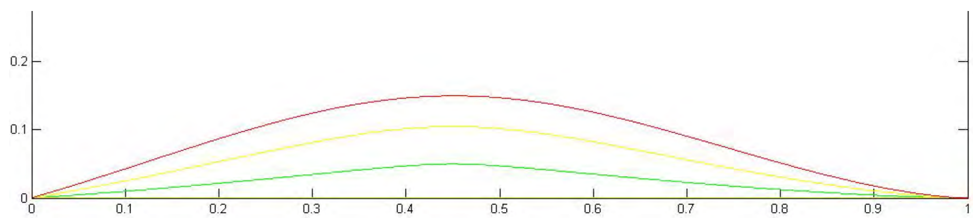

Figure 2 Examples of bodies of revolution at different values of the thickness ratio *D/L*, similar to the unseparated shape UA-2, [18]. The dimensionless (based on the body length *L*) radius is shown versus the dimensionless coordinate *x/L*.

The attached flow pattern allows delaying the boundary layer turbulisation (see, [17, 18]) and reducing also the friction drag (the pressure drag of the unseparated shapes is close to zero due to the D'Alembert paradox). Then the total drag on such laminar unseparated body of revolution can be estimated with the following formula [18, 20]:

$$C_V \approx \frac{4.7}{\sqrt{\mathrm{Re}_V}}, \quad \mathrm{Re}_V = UV^{1/3}/\nu \tag{4}$$

where ν is the kinematic viscosity coefficient of water. Equation (4) is in good agreement with the Hoerner formula [21] for the laminar drag on the standard elongated bodies of revolution.

Putting (4) into (1) allows us to obtain, [16]:

$$1/k = 2.35\nu^{1/2}U^{3/2}V^{-1/2}g^{-1} \tag{5}$$

Estimation (5) can be treated as minimal possible value of the drag-weight ratio not only for the vehicles with underwater hulls, since the drag of the floating hulls is greater due to the wave resistance. Formula (5) shows that the simplest way to reduce the energetic needs and pollution is to use special shaped laminar unseparated hulls with low speeds and large volumes.

In order to have laminar boundary layer on the entire hull surface, speed, length and volume of such hulls are related by the inequaility, [16, 17]:

$$V < \frac{59558\pi L^3}{\mathrm{Re}_L} = \frac{59558\pi\nu L^2}{U} \tag{6}$$

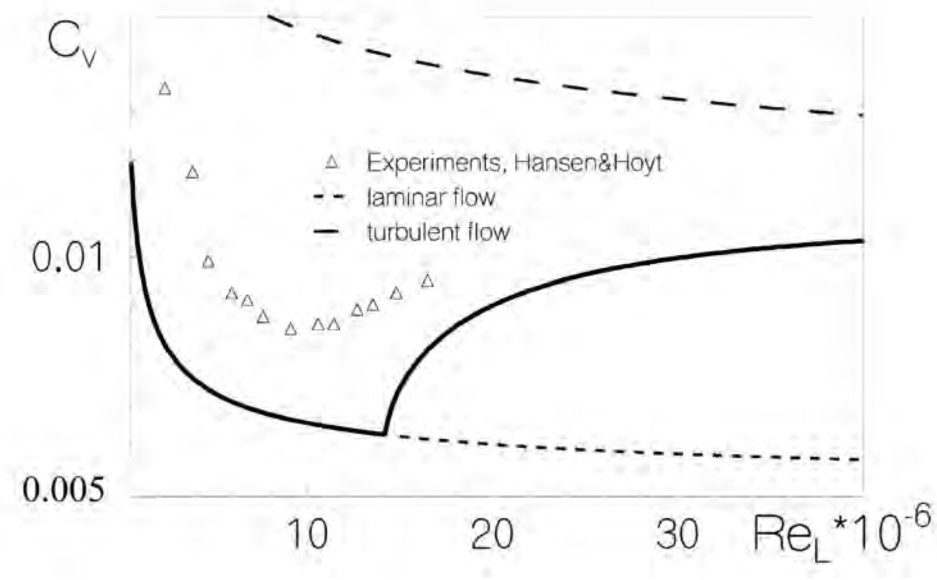

Figure 3 Drag coefficient estimations for a body of revolution similar to the shape of Dolphinus delphis ponticus Barab. and comparison with the experimental measurements of drag on the Hansen&Hoyt model [22].

To estimate possible drag reduction an axisymmetric shape similar to the body of Dolphinus delphis ponticus Barab. [7] was taken to calculate the critical Reynolds number according to relationship (6). If $\mathrm{Re}_L < 1.4 \cdot 10^7$, the boundary layer is laminar on the entire body surface and its drag can be estimated by (4), see laminar curve in Fig. 3. With increasing the Reynolds number, the turbulent boundary layer zone near the tail expands and leads to the drag increase. Simple estimations of the turbulent drag in this zone can be done with the flat plate concept [21] and are also shown in Fig. 3. Comparison with the experimental drag measurements on the Hansen&Hoyt body [22] show that special shaped unseparated hulls can ensure almost twice lower drag.

5. CHARACTERISTICS OF A SWATH ELECTRICAL YACHT

In the case of recreation yachts, the velocity demand is not very high, and it is possible to achieve very small values $1/k$, provided the hulls are laminar and unseparated. For example, at speed *U*=10m/s; volume of the special shaped underwater hull *V*=2m^3 and its length *L*=9.2 m; $\nu > 1.3 \cdot 10^{-6}$ m^2/s, the inequality (6) holds. It means, that laminar attached flow is expected and equation (5) can be used to estimate the commercial efficiency of the SWATH yacht. Simple calculations yield the value $k \approx 165$, which is approximately 3 times higher than the estimation of lift-to-drag ratio for Solar Impulse 2 plane, [23], which rounded globe with the use of solar energy only. Thus, such yacht can use electrical engines only and reduce the pollution. It is possible to use solar sells to charge the batteries for the same yacht. The solar cells can be fixed on the overwater hull, on the special folding panels (during the stops).

In order to reduce the drag in air, a special shaped overwater hull can be used. For example, at the chosen values of speed *U*=10m/s and length *L*=9.2 m, the volume of the special shaped overwater hull V_a could be 23m^3. Then the inequality (5) holds at the kinematic viscosity of air greater than $1.47 \cdot 10^{-5}$ m^2/s (at temperatures higher than 15^{o}C).

The sketch of the yacht is shown in Fig. 4. Its main characteristics are: the speed *U*=10m/s, weight 4t, length 9.2 m, two underwater hulls with the volume *V*=2m^3 and maximal diameter 0.92m (*L/D*=10). Two electrical engines and propellers located on the tails of underwater hulls are used for propulsion. The vehicle has one overwater hull of the same length, maximal diameter 2.6 m and volume 23 m^3. It must be noted that there is no need to use very slender hulls and there are no problems with their strength and stability.

The proposed technology could have a huge area of application, since it is economically efficient, green and comfortable (due to the high seakeeping). The Froude number is approximately 1.05 and is much higher than the critical value for the conventional ships (approximately 0.4-0.5; at higher Froude numbers the wave drag increases drastically). It means that conventional yachts of same speed must be at least 4 times longer to avoid huge increase in wave drag.

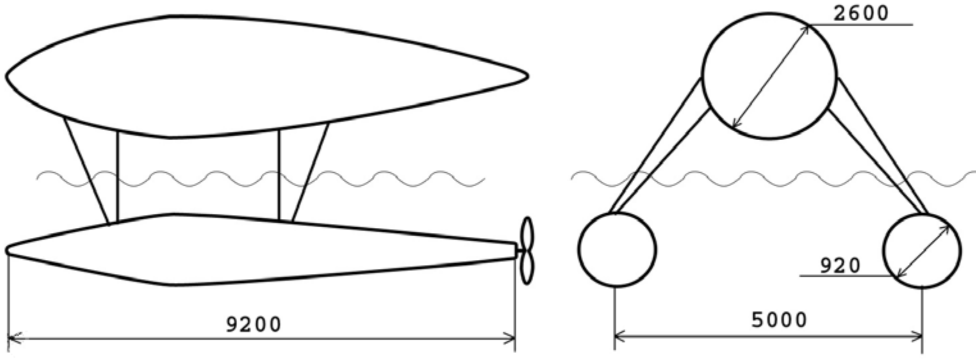

Figure 4 Sketch of SWATH electrical yacht.

6. CONCLUSION

The proposed SWATH electrical yacht with special shaped underwater hulls could have a huge area of application, since it is economically efficient, green and comfortable (due to the high seakeeping). The Froude number of such yachts can be much higher than the critical value for the conventional ships. The realized yacht (or its self-propulsion model) could also be a prototype for faster and larger SWATH ferries.

REFERENCES

1. Michael Le Page. France and others plan to tackle air pollution in Mediterranean sea. https://www.newscientist.com /article/2191427-france-and-others-plan-to-tackle-air-pollution-in-mediterranean-sea/
2. Croatia country briefing - The European environment — state and outlook 2015. https://www.eea.europa.eu/soer-2015/countries/croatia
3. Fred Lambert. All-electric ferry cuts emission by 95% and costs by 80%, brings in 53 additional orders. Feb. 3rd 2018
4. https://electrek.co/2018/02/03/all-electric-ferry-cuts-emission-cost/
5. Fred Lambert. A new all-electric cargo ship with a massive 2.4 MWh battery pack launches in China. Dec. 4th 2017. https://electrek.co/2017/12/04/all-electric-cargo-ship-battery-china/
6. Gabrielly, Y. & von Karman, Th. What price speed. *Mechanical Engineering*. USA. Vol. 72. No. 10, 1950. P. 775-779.
7. https://www.atlanticyachtandship.ru/catalog/file/227371/ghost-juliet_marine-english.pdf
8. Aleyev, Yu. G. *Nekton*. Dr. W. Junk, The Hague, 1977.
9. Rohr, J. & Latz, M. I. & Fallon, S. & Nauen, J. C. Experimental approaches towards interpreting dolphin stimulated bioluminescence. *J. Exper. Biology.* Vol. 201. 1998. P. 1447-1460.
10. Loitsyanskiy, L. G. *Mechanics of Liquids and Gases*, Begell House, New York and Wallingford, 6th ed, 1995.
11. Landau, L. D. & Lifshits, E. M. *Fluid Mechanics, Second Edition: Volume 6 (Course of Theoretical Physics)*, Butterworth-Heinemann. 1987.
12. Zedan, M. F. & Seif, A. A. & Al-Moufadi, S. Drag Reduction of Fuselages Through Shaping by the Inverse Method. *J. of Aircraft*. Vol. 31. No. 2. 1994. P. 279-287.
13. Lutz, Th. & Wagner, S. Drag Reduction and Shape Optimization of Airship Bodies. *J. of Aircraft*. Vol. 35. No. 3. 1998. P. 345-351,
14. Goldschmied, F. R. Integrated hull design, boundary layer control and propulsion of submerged bodies: Wind tunnel verification. In: *AIAA (82-1204), Proceedings of the AIAA/SAE/ASME 18th Joint Propulsion Conference.* P. 3-18. 1982.
15. Nesteruk, I. Rigid Bodies without Boundary-Layer Separation. *Int. J. of Fluid Mechanics Research.* Vol. 41. No. 3. 2014. P. 260-281.
16. Saibene, F. & Minetti, A. E. Biomechanical and physiological aspects of legged locomotion in humans", *Eur Journal Appl Physiol*. Vol. 88. 2003. P. 297-316. DOI 10.1007/s00421-002-0654-9
17. Nesteruk, I. Efficiency of Steady Motion and its Improvement with the Use of Unseparated and Supercavitating Flow Patterns, Naukovi Visti NTUU KPI. 2016. No. 6. P. 51-67. DOI: http://dx.doi.org/10.20535/1810-0546.2016.6.81605
18. 17. I. Nesteruk, "Peculiarities of Turbulization and Separation of Boundary-Layer on Slender Axisymmetric Subsonic Bodies", *Naukovi visti, NTUU "Kyiv Polytech. Inst."* No. 3, pp. 70-76, 2002 (in Ukrainian).
19. Nesteruk, I. & Passoni, G. & Redaelli. A. Shape of Aquatic Animals and Their Swimming Efficiency, *Journal of Marine Biology.* 2014. Article ID 470715. doi:10.1155/2014/470715.
20. I. Nesteruk, M. Brühl, Th. Möller. Testing a special shaped body of revolution similar to dolphins trunk, *KPI Science News*, No. 2, 2018, pp.44-53. https://doi.org/10.20535/1810-0546.2018.2.129140
21. I. Nesteruk, Reserves of the hydrodynamical drag reduction for axisymmetric bodies, *Bulletin of Kiev University, Series: Physics & Mathematics*, No.1, pp. 112–118, 2002
22. Hoerner, S. F. *Fluid-dynamic drag*, Midland Park, N.J. 1965. 416 p.
23. Hansen, R. J. & Hoyt, J. G. (1984). Laminar-To-Turbulent Transition on a Body of Revolution with an Extended Favorable Pressure Gradient Forebody. *Journal of Fluids Engineering.* Vol. 106. P. 202-210.
24. Available at: https://en.wikipedia.org/wiki/Solar_Impulse

ANALYSIS OF AUXILIARY EXERGY FLOW STREAM DURING THE CHANGE IN MARINE STEAM PROPULSION SYSTEM LOAD

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Summary

The paper presents analysis of steam auxiliary exergy flow stream during the change in marine steam propulsion system load. The change in auxiliary steam exergy flow from marine steam generators during the increase in steam system load is compared with the change in main steam exergy flow. Exergy flow stream to each auxiliary device in steam system is analysed and operation dynamics of auxiliary devices are explained. The presented analysis provides an insight into operation of each observed marine steam system auxiliary device from the lowest to the highest steam system load.

Keywords: Marine steam propulsion, Load change, Exergy flow, Auxiliary steam systems

1. INTRODUCTION

Steam power systems today are the mostly land-based and its main function is electricity production, [1] and [2]. Marine power systems are mainly based on internal combustion engines with a lot of different variations in power and operational principle, [3] and [4]. Marine steam propulsion systems are relatively rare, but due to a lot of advantages they are dominant on LNG carriers [5] and [6]. As a land-based steam power system, each marine steam propulsion system consists of many components, necessary for safe and reliable operation [7] and [8].

The marine steam propulsion system consists of two steam flow streams from steam generators - main and auxiliary [9]. The main flow stream is used for steam turbines operation [10] and [11], while auxiliary steam flow stream is used for proper operation of auxiliary marine equipment [12] and [13]. The auxiliary steam flow stream has a lower pressure and temperature in comparison with a main one [14]. For both flow streams, it is interesting to analyse its operation dynamics during the change in marine steam system load.

In this paper an analysis of steam auxiliary exergy flow stream during the change in marine steam propulsion system load is presented. Steam auxiliary exergy flow stream and its dynamic is compared with the main exergy flow stream. Exergy flow stream to each auxiliary device in steam system was calculated and analysed. Operation dynamics of auxiliary devices and share of the current auxiliary exergy flow, from steam generators to each auxiliary device, are explained. This analysis provides an insight into operation of marine steam system auxiliary devices from the lowest to the highest steam system load.

2. MAIN AND AUXILIARY EXERGY FLOW STREAMS IN MARINE STEAM PROPULSION SYSTEM

Steam propulsion system in which main and auxiliary exergy flow streams were analysed is mounted on the conventional LNG carrier. Main characteristics and specifications of the LNG carrier are presented in Table 1.

Table 1 LNG carrier main characteristics and specifications

Dead weight tonnage	84812 DWT
Overall length	288 m
Max breadth	44 m
Design draft	9.3 m
Steam generators	2 x Mitsubishi MB-4E-KS
Propulsion turbine	Mitsubishi MS40-2 (max. power 29420 kW)

Steam flow streams which leave steam generators in marine propulsion system are main and auxiliary flow streams. Main steam flow stream represents a steam with maximum pressure and temperature. The auxiliary steam flow stream is produced from main flow stream in a way that part of produced main steam is sent back to the steam generators. That steam passes through steam drums and transfers heat to feed water. Due to heat transfer, steam temperature and pressure decreases. The auxiliary steam flow stream is used for the operation of auxiliary steam system devices. Those devices require steam with lower temperature and pressure when compared to main steam stream.

In marine steam propulsion system, auxiliary steam flow is used in the atomizing steam system, dump system, deaerator, desuperheater and air heater, Fig. 1. Operation principle of each auxiliary device is:

- Atomizing steam system: at atomizing steam system represents a small amount of auxiliary steam from steam generators that is used for fuel oil atomizing and for cooling of burners when they are not in use.
- Dump line: At low steam system loads, steam generators produce more steam than an entire system requires. Steam excess is led directly to the main steam condenser through the steam system dump line.
- Deaerator: Deaerator is a component which uses auxiliary steam from steam generators for feed water heating and for gas removal from feed water in order to avoid cavitation.
- Desuperheater: Desuperheater is an open heater (with direct mixing of auxiliary steam and water). Desuperheater in the marine steam system is used to prepare auxiliary steam for additional heating purposes.
- Air heater: Before entrance in each steam generator combustion chamber, air is heated in air heater by auxiliary steam. Heating medium is auxiliary steam only, because flue gas temperature is not sufficient for air heating purposes.

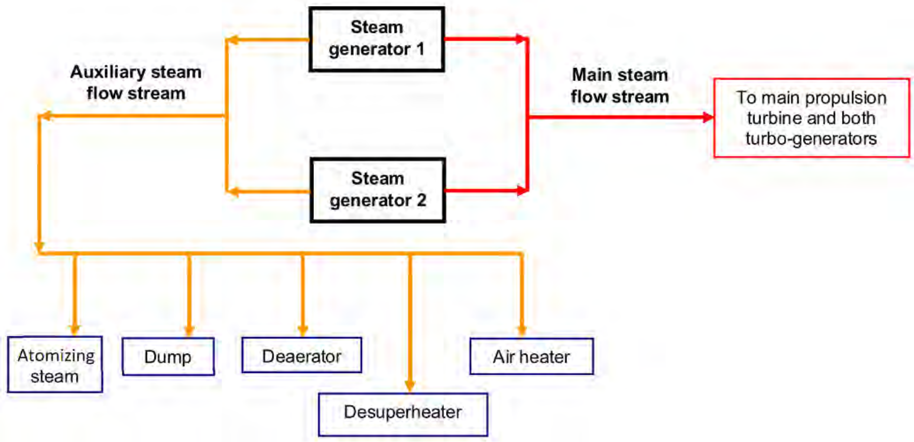

Figure 1 Scheme of marine steam generators with main and auxiliary steam flow streams

3. EXERGY FLOW STREAMS NUMERICAL ANALYSIS

3.1. Governing equations of exergy analysis

Mass flow rate balance equation for any flow stream is expressed as [15]:

$$\sum \dot{m}_{\mathrm{IN}} = \sum \dot{m}_{\mathrm{OUT}} \tag{1}$$

The second law of thermodynamics defines exergy analysis [16]. The main exergy balance equation is [17]:

$$\dot{X}_{\mathrm{heat}} - P = \sum \dot{m}_{\mathrm{OUT}} \cdot \varepsilon_{\mathrm{OUT}} - \sum \dot{m}_{\mathrm{IN}} \cdot \varepsilon_{\mathrm{IN}} + \dot{E}_{\mathrm{ex,D}} \tag{2}$$

where the net exergy transfer by heat ( ) at the temperature T is [18]:

$$\dot{X}_{\mathrm{heat}} = \sum (1 - \frac{T_0}{T}) \cdot \dot{Q} \tag{3}$$

According to [19], specific exergy is defined as:

$$\varepsilon = (h - h_0) - T_0 \cdot (s - s_0) \tag{4}$$

The exergy power of a flow, according to [20] is:

$$\dot{E}_{\mathrm{ex}} = \dot{m} \cdot \varepsilon = \dot{m} \cdot \left[(h - h_0) - T_0 \cdot (s - s_0) \right] . \tag{5}$$

3.2. Calculation of main and auxiliary exergy flow streams

Exergy power of main and auxiliary steam flow stream was calculated by using measured steam pressures, temperatures and mass flow rates, according to equation (5). Steam specific enthalpies and specific entropies were calculated from measured steam pressures and temperatures by using NIST REFPROP software [21].

Throughout this paper, exergy power values are presented for both steam generators (cumulative exergy power). A steam flow stream which enters to any system device was produced by both steam generators. Therefore, only the cumulative flow streams can be relevant in the steam system exergy analysis.

Auxiliary steam specific enthalpy and specific entropy are not the same as at the steam generator's outlet, when compared to flow streams to each auxiliary device, due to losses through the pipeline. Decrease in auxiliary steam pressure and temperature in the pipeline (and consequentially decrease in specific enthalpy and specific entropy) is small and in this paper is neglected. Auxiliary steam flow streams to each auxiliary device were calculated with the same specific enthalpy and specific entropy as at the steam generator's outlet, but with corresponding steam mass flow rates.

Cumulative steam mass flow rate, which exits from both steam generators, is defined as:

$$\dot{m}_{\mathrm{CU}} = \dot{m}_{\mathrm{MA}} + \dot{m}_{\mathrm{AUX}} \tag{6}$$

Cumulative steam exergy power from steam generators is:

$$\dot{E}_{\mathrm{ex,CU}} = \dot{E}_{\mathrm{ex,MA}} + \dot{E}_{\mathrm{ex,AUX}} \tag{7}$$

where cumulative main and auxiliary steam exergy power are defined as:

$$\dot{E}_{\mathrm{ex,MA}} = \dot{m}_{\mathrm{MA}} \cdot \varepsilon_{\mathrm{MA}} \tag{8}$$

$$\dot{E}_{\mathrm{ex,AUX}} = \dot{m}_{\mathrm{AUX}} \cdot \varepsilon_{\mathrm{AUX}} \tag{9}$$

The share of cumulative main steam exergy power in cumulative exergy power from steam generators is:

$$SH_{\mathrm{MA}} = \frac{\dot{E}_{\mathrm{ex,MA}}}{\dot{E}_{\mathrm{ex,CU}}} \cdot 100 \tag{10}$$

The share of cumulative auxiliary steam exergy power in cumulative exergy power from steam generators is:

$$SH_{\mathrm{AUX}} = \frac{\dot{E}_{\mathrm{ex,AUX}}}{\dot{E}_{\mathrm{ex,CU}}} \cdot 100 \tag{11}$$

Cumulative auxiliary steam flow stream is divided on flow streams to each auxiliary device (auxiliary devices are atomizing steam system, dump, deaerator, desuperheater and air heater), Fig. 1.

Mass flow rate balance for cumulative auxiliary steam flow stream is:

$$\dot{m}_{\mathrm{AUX}} = \dot{m}_{\mathrm{AS}} + \dot{m}_{\mathrm{DU}} + \dot{m}_{\mathrm{DEA}} + \dot{m}_{\mathrm{DES}} + \dot{m}_{\mathrm{AH}} \tag{12}$$

The change in auxiliary steam pressure and temperature through the pipeline is neglected, so cumulative auxiliary steam exergy power divided to each auxiliary device is:

$$\dot{E}_{\mathrm{ex,AUX}} = \dot{m}_{\mathrm{AUX}} \cdot \varepsilon_{\mathrm{AUX}} = \left(\dot{m}_{\mathrm{AS}} + \dot{m}_{\mathrm{DU}} + \dot{m}_{\mathrm{DEA}} + \dot{m}_{\mathrm{DES}} + \dot{m}_{\mathrm{AH}}\right) \cdot \varepsilon_{\mathrm{AUX}} \tag{13}$$

Steam exergy power to each auxiliary device is then:

$$\dot{E}_{\mathrm{ex,AD}} = \dot{m}_{\mathrm{AD}} \cdot \varepsilon_{\mathrm{AUX}} \tag{14}$$

The share of each auxiliary device exergy power in the entire (cumulative) auxiliary exergy power is:

$$SH_{\mathrm{AD}} = \frac{\dot{E}_{\mathrm{ex,AD}}}{\dot{E}_{\mathrm{ex,AUX}}} \cdot 100 \ . \tag{15}$$

Exergy analysis depends greatly on the ambient state (pressure and temperature of the ambient) in which system operates. The ambient state in the LNG carrier engine room during the measurements was:

- pressure: p_0 = 0.1 MPa = 1 bar,
- temperature: T_0 = 25 °C = 298.15 K.

4. REQUIRED MEASUREMENT RESULTS OF MAIN AND AUXILIARY STEAM FLOW STREAMS

Steam temperature, pressure and mass flow rate at each steam system load were measured with equipment already mounted on the steam system pipeline. The same equipment is used for control and regulation of the entire steam system during LNG carrier exploitation. Steam operating parameters are presented in relation to propulsion propeller speed. Increase in propulsion propeller speed is directly proportional to increase in steam system load and vice versa.

Table 2 present measurement results of main and auxiliary steam flow streams. Cumulative auxiliary steam flow stream is divided on flow streams to each auxiliary device. Losses of steam pressure and temperature in auxiliary steam pipeline are small and in this paper are neglected. Therefore, for exergy power calculation it was necessary to measure only steam mass flow rate to each device.

Table 2 Measurement results for main and auxiliary steam flow streams

Propulsion propeller speed (rpm)	Main steam flow stream			Auxiliary steam flow stream-cumulative			Atomizing steam mass flow rate (kg/h)	Dump steam mass flow rate (kg/h)	Deaerator steam mass flow rate (kg/h)	Desuperheater steam mass flow rate (kg/h)	Air heater steam mass flow rate (kg/h)
	Steam temperature (°C)	Steam pressure (MPa)	Steam mass flow rate (kg/h)	Steam temperature (°C)	Steam pressure (MPa)	Steam mass flow rate (kg/h)					
25.00	501	6.20	16744	313	6.01	29876	428	15764	5881	3022	4781
34.33	500	6.20	22696	309	6.08	27710	441	13178	6467	2797	4827
41.78	500	6.19	29394	304	6.11	17708	416	3696	6049	2687	4860
53.50	509	6.10	47985	297	6.07	12170	442	0	3639	2792	5297
56.65	498	5.98	40363	297	5.94	17038	475	0	8392	2796	5375
61.45	500	5.98	49438	297	5.94	14486	472	0	5367	2685	5962
62.52	499	5.99	48977	299	5.95	14528	470	0	5282	2903	5873
63.55	500	5.99	52080	298	5.95	14915	478	0	5657	2677	6103
65.10	504	6.10	54438	299	6.10	15633	470	0	6318	2587	6258
66.08	515	6.08	56078	300	6.04	16133	489	0	6541	2690	6413
67.68	515	6.08	59201	301	6.04	16756	494	0	6983	2797	6482
68.66	516	6.09	61300	302	6.05	13618	488	0	3840	2685	6605
69.49	515	6.09	62723	302	6.05	14039	483	0	4077	2792	6687
70.37	516	6.09	64366	302	6.05	14150	472	0	4078	2688	6912
71.03	516	6.10	65019	302	6.06	13954	464	0	3994	2687	6809
73.09	515	6.10	70515	301	6.07	14690	494	0	4484	2584	7128
74.59	515	6.07	77211	299	6.04	10641	491	0	0	2688	7462
76.56	515	6.07	82881	299	6.04	10848	468	0	0	2793	7587
78.41	515	6.09	89907	299	6.06	10744	472	0	0	2687	7585
79.46	498	5.94	95990	298	5.92	3273	479	0	0	2794	0
80.44	502	6.00	100540	297	5.94	3384	478	0	0	2906	0
81.49	500	5.99	102883	290	5.99	483	483	0	0	0	0
82.88	501	5.99	108601	280	5.99	474	474	0	0	0	0
83.00	501	5.99	109961	280	5.99	477	477	0	0	0	0

5. MAIN AND AUXILIARY STEAM FLOW STREAMS EXERGY ANALYSIS RESULTS WITH THE DISCUSSION

The mass flow rate difference between main and auxiliary steam flow streams can be seen in Fig. 2. At the lowest observed propulsion propeller speeds this difference is negative (25.00 rpm and 34.33 rpm) because at the propulsion system start-up, mass flow rate of the auxiliary steam flow stream is higher. Increase in propulsion system load resulted with an increase in mass flow rate of main steam stream (from 41.78 rpm to the highest system load). At the highest observed steam system load, the mass flow rate difference between main and auxiliary steam flow stream is the highest and amounts 109484 kg/h, Table 2.

It should be noted that the increase in propulsion system load resulted in a proportional increase of main steam mass flow rate (with the exception of just a few operating points at middle load), which means that steam system turbines use more and more steam. At high steam system loads, the majority of analysed auxiliary devices in this study get steam for its operation from the main turbine subtractions. Following the operation principle of this steam propulsion system, it can be concluded that increase in main and the decrease in auxiliary steam mass flow rate during the load increase is expected.

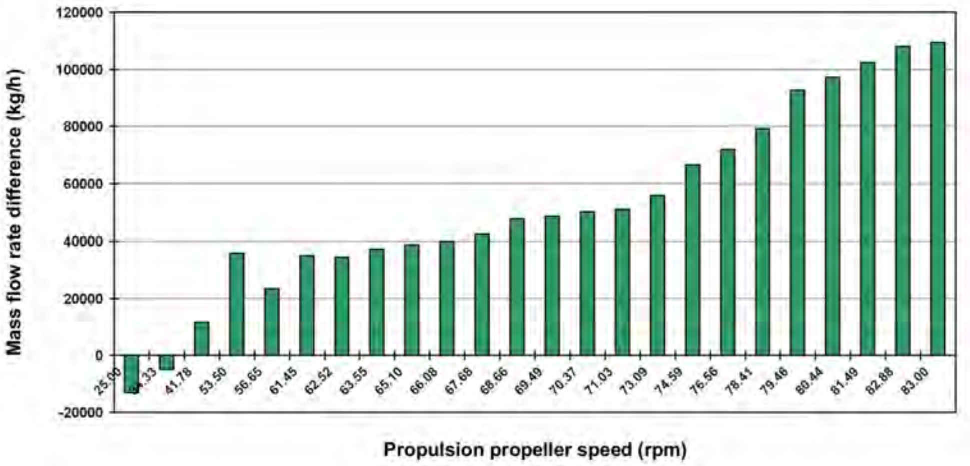

Figure 2 Mass flow rate difference between main and auxiliary steam flow stream

Main and auxiliary exergy power of steam flow streams was calculated according to equations (8) and (9). Increase in steam system load resulted with increase in main flow stream exergy power, while at the same time auxiliary flow stream exergy power decreases, Fig. 3.

Only at the lowest observed load at 25.00 rpm, exergy power of the auxiliary flow stream is higher than exergy power of the main flow stream. From the lowest to the highest steam system load, exergy power of main steam flow stream increases from 6418.53 kW up to 42057.03 kW, while exergy power of the auxiliary flow stream decreases from 9147.04 kW up to 137.26 kW. At high steam system load exergy power of the auxiliary steam flow stream is so small in comparison with the exergy power of the main steam flow stream that it can be declared as negligible.

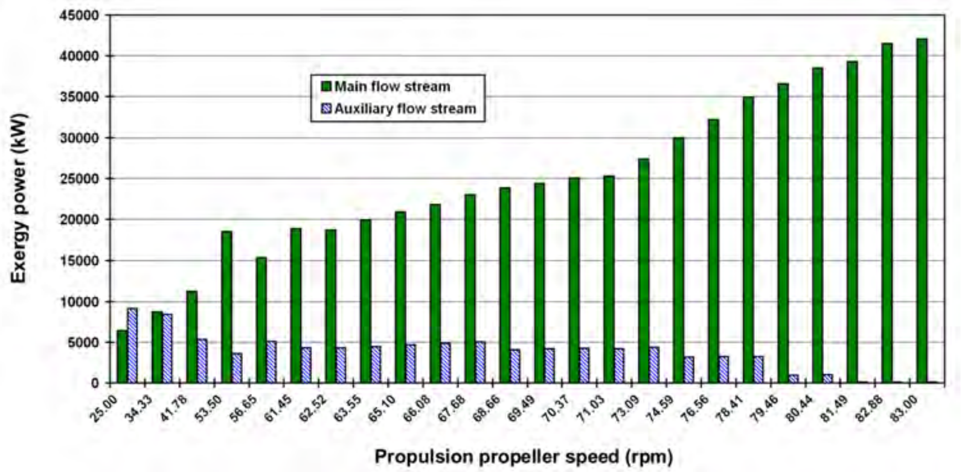

Figure 3 Change in exergy power of main and auxiliary steam flow stream

Analysis of auxiliary steam exergy power which was transferred from steam generators to each auxiliary device must be presented in two parts, for lower and for higher propulsion propeller speeds, Fig. 4 and Fig. 5.

At the lowest propulsion propeller speeds (25.00 rpm and 34.33 rpm) the highest auxiliary steam exergy power is sent to the main condenser through dump line (4826.41 kW and 4010.50 kW), Fig. 4. That amount of auxiliary steam exergy power is lost because at the lowest loads it is not required in the steam system. It can also be seen from Fig. 4 that increase in system load resulted with a decrease in dump exergy power and already on 41.78 rpm dump exergy power is not the dominant one. After 41.78 rpm, dump line is closed because from that moment on, all produced steam exergy power is used in the steam system.

After dump line at low propulsion propeller speeds, the most dominant amount of auxiliary steam exergy power is sent to deaerator and air heater. Atomizing steam system at low steam system loads takes a significantly smaller amount of auxiliary steam exergy power in comparison to other auxiliary components.

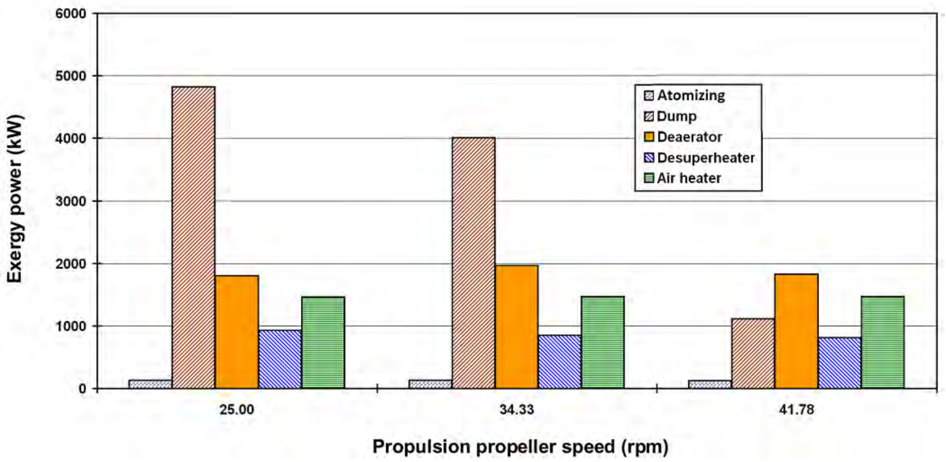

Figure 4 Steam exergy power to each auxiliary device - low propulsion propeller speeds

At middle and high propulsion system loads (from 53.50 rpm up to 83.00 rpm) dump line is closed and the auxiliary steam exergy power is sent to other auxiliary devices, Fig. 5. The greatest consumers of auxiliary steam exergy power are deaerator and air heater, after which follows desuperheater. The atomizing steam system uses almost constant auxiliary steam exergy power in the entire area of middle and high steam system loads. At the highest observed propulsion system loads atomizing steam system is the only auxiliary device which consumes auxiliary steam exergy power.

Auxiliary steam from steam generators is sent to auxiliary devices until the moment when each auxiliary device (with an exception of the atomizing steam system) gets steam for its operation from the main steam turbine subtractions. The first device which gets steam for its operation from a main steam turbine is deaerator after 73.09 rpm. After deaerator, main steam turbine subtraction brings steam to the air heater after 78.41 rpm. The auxiliary device which gets steam from the main turbine the latest is desuperheater and this occurrence happens after 80.44 rpm. Only the atomizing steam system gets auxiliary steam for its operation from the steam generators the entire time, irrespective of steam system load.

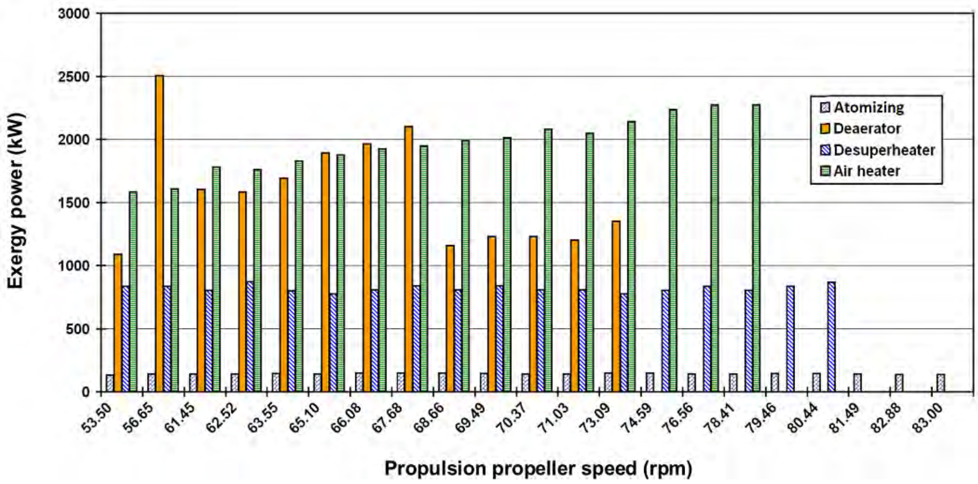

Figure 5 Steam exergy power to each auxiliary device - middle and high propulsion propeller speeds

At three different steam system loads (at three different propulsion propeller speeds) the share of each auxiliary device in current cumulative auxiliary steam exergy power is presented in Fig. 6, Fig. 7 and Fig. 8.

At the lowest observed steam system load (25.00 rpm) dump system takes the most significant share of current cumulative auxiliary steam exergy power with 53%, Fig. 6. At this propulsion system load, the deaerator takes 20% and air heater takes 16% of cumulative auxiliary steam exergy power. The atomizing steam system has the lowest share in cumulative auxiliary steam exergy power (only 1%) at the lowest observed propulsion propeller speed as measurements were taken on dual burning mode, with minimum fuel and maximum gas mode, what results in only small mass variation of that system during all measured modes.

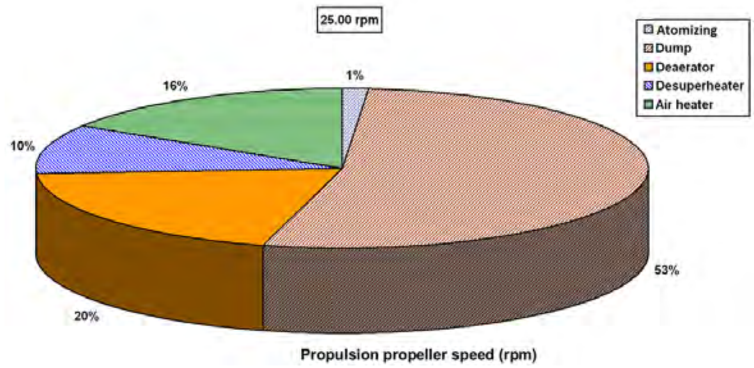

Figure 6 Share in the cumulative auxiliary exergy power of each auxiliary device - propulsion propeller speed of 25.00 rpm

At middle steam system load of 65.10 rpm, Fig. 7, dump line is closed and all steam exergy power produced in the steam generators (main and auxiliary) is used in the steam system. At observed system load, deaerator and air heater take the highest share in current cumulative auxiliary steam exergy power (40% each). In desuperheater goes 17% of cumulative auxiliary steam exergy power, while the atomizing steam system takes a share of 3%. When compared with the lower steam system load, it can be concluded that share in current cumulative auxiliary steam exergy power of each auxiliary device increases with an increase in steam system load.

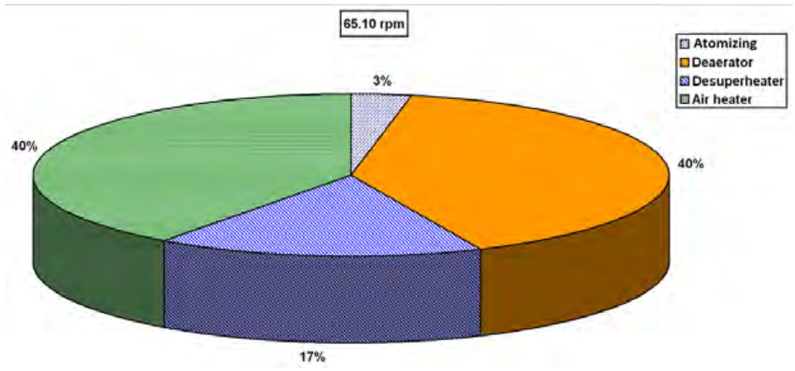

Figure 7 Share in the cumulative auxiliary exergy power of each auxiliary device - propulsion propeller speed of 65.10 rpm

At propulsion propeller speed of 78.41 rpm, auxiliary steam flow is sent to just three auxiliary devices (air heater, desuperheater and the atomizing steam system). Air heater takes the highest share in current cumulative auxiliary steam exergy power with 71%, Fig. 8. Desuperheater takes 25% and atomizing steam system takes 4% of current cumulative auxiliary steam exergy power.

At the highest observed propulsion propeller speeds (from 81.49 rpm to 83.00 rpm) cumulative auxiliary steam exergy power is sent only to atomizing steam system, so its share in that steam system operation area is 100%.

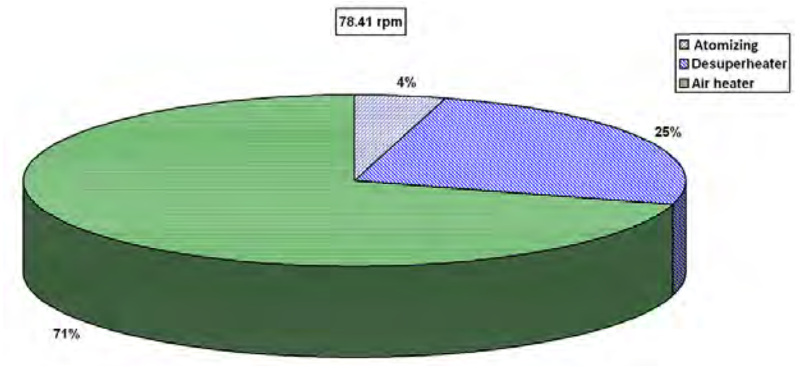

Figure 8 Share in the cumulative auxiliary exergy power of each auxiliary device - propulsion propeller speed of 78.41 rpm

6. CONCLUSION

This paper presents an analysis of steam auxiliary exergy flow stream during the change in marine steam propulsion system load.

At low propulsion propeller speeds the highest auxiliary steam exergy power is sent to the main condenser through dump line. That amount of auxiliary steam exergy power is lost because at the lowest loads it is not required in the steam system. After dump system, at low system loads the most dominant amount of auxiliary steam exergy power is sent to the deaerator and air heater while the atomizing steam system takes a significantly smaller amount of auxiliary steam exergy power in comparison to other components.

At middle and high propulsion system loads, dump line is closed and the greatest consumers of auxiliary steam exergy power are deaerator and air heater, after which follows desuperheater. The atomizing steam system uses low and almost constant auxiliary steam exergy power in the entire area of middle and high steam system loads due to dual burning mode, with minimum fuel and maximum gas mode. At the highest observed system loads atomizing steam system is the only auxiliary device which consumes auxiliary steam exergy power.

Auxiliary steam from steam generators is sent to auxiliary devices until the moment when each auxiliary device (with an exception of the atomizing steam system) gets a steam for its operation from the main steam turbine subtractions.

Share in current cumulative auxiliary steam exergy power of each auxiliary device increases with an increase in steam system load.

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Nomenclature

Abbreviations:

LNG Liquefied Natural Gas

Latin Symbols:

$\dot{E}$ stream flow power, kJ/s
h specific enthalpy, kJ/kg
$\dot{m}$ mass flow rate, kg/s or kg/h
p pressure, MPa
P power, kJ/s
$\dot{Q}$ heat transfer, kJ/s
s specific entropy, kJ/kg•K
SH share, %
T temperature, °C or K
$\dot{X}_{\mathrm{heat}}$ heat exergy transfer, kJ/s

Greek symbols:

ε specific exergy, kJ/kg

Subscripts:

0 ambient conditions
AD Auxiliary device
AH Air heater
AUX Auxiliary
CU Cumulative
D destruction (losses)
DEA Deaerator
DES Desuperheater
DU Dump
ex exergy
IN inlet (input)
MA Main
OUT outlet (output)
AS Atomizing steam

REFERENCES

[1] Kumar, S., Kumar, D., Memon, R. A., Wassan, M. A., Ali, M. S.: Energy and Exergy Analysis of a Coal Fired Power Plant, Mehran University Research Journal of Engineering & Technology 37 (4), p. 611-624, 2018. (doi:10.22581/muet1982.1804.13)

[2] Ahmadi, G., Toghraie, D., Akbari, O. A.: Solar parallel feed water heating repowering of a steam power plant: A case study in Iran, Renewable and Sustainable Energy Reviews 77, p. 474–485, 2017. (doi:10.1016/j.rser.2017.04.019)

[3] Mrzljak, V., Medica, V., Bukovac, O.: Simulation of a Two-Stroke Slow Speed Diesel Engine Using a Quasi-Dimensional Model, Transactions of Famena, 2, p. 35-44, 2016. (doi:10.21278/TOF.40203)

[4] Mrzljak, V., Medica, V., Bukovac, O.: Volume agglomeration process in quasi-dimensional direct injection diesel engine numerical model, Energy 115, p. 658-667, 2016. (doi:10.1016/j.energy.2016.09.055)

[5] Koroglu, T., Sogut, O. S.: Conventional and Advanced Exergy Analyses of a Marine Steam Power Plant, Energy 163, p. 392-403, 2018. (doi:10.1016/j.energy.2018.08.119)

[6] Mrzljak, V., Poljak, I., Mrakovčić, T.: Energy and exergy analysis of the turbo-generators and steam turbine for the main feed water pump drive on LNG carrier, Energy Conversion and Management 140, p. 307–323, 2017. (doi:10.1016/j.enconman.2017.03.007)

[7] Mrzljak, V., Poljak, I., Medica-Viola, V.: Dual fuel consumption and efficiency of marine steam generators for the propulsion of LNG carrier, Applied Thermal Engineering, 119, p. 331–346, 2017. (doi:10.1016/j.applthermaleng.2017.03.078)

[8] Poljak, I., Orović, J., Mrzljak, V.: Energy and Exergy Analysis of the Condensate Pump During Internal Leakage from the Marine Steam Propulsion System, Scientific Journal of Maritime Research 32 (2), p. 268-280, 2018. (doi:10.31217/p.32.2.12)

[9] Mrzljak, V., Prpić-Oršić, J., Senčić, T.: Change in Steam Generators Main and Auxiliary Energy Flow Streams During the Load Increase of LNG Carrier Steam Propulsion System, Scientific Journal of Maritime Research 32 (1), p. 121-131, 2018. (doi:10.31217/p.32.1.15)

[10] Mrzljak, V., Poljak, I., Prpić-Oršić, J.: Exergy analysis of the main propulsion steam turbine from marine propulsion plant, Shipbuilding: Theory and Practice of Naval Architecture, Marine Engineering and Ocean Engineering Vol. 70., No. 1, p. 59-77, 2019. (doi:10.21278/brod70105)

[11] Mrzljak, V.: Low power steam turbine energy efficiency and losses during the developed power variation, Technical Journal 12 (3), p. 174-180, 2018. (doi:10.31803/tg-20180201002943)

[12] Mrzljak, V., Poljak, I., Medica-Viola, V.: Thermodynamical analysis of high-pressure fed water heater in steam propulsion system during exploitation, Shipbuilding: Theory and Practice of Naval Architecture, Marine Engineering and Ocean Engineering 68 (2), p. 45-61, 2017. (doi:10.21278/brod68204)

[13] Mrzljak, V., Poljak, I., Medica-Viola, V.: Efficiency and losses analysis of low-pressure feed water heater in steam propulsion system during ship maneuvering period, Scientific Journal of Maritime Research 30, p. 133-140, 2016. (doi:10.31217/p.30.2.6)

[14] Orović, J., Mrzljak, V., Poljak, I.: Efficiency and Losses Analysis of Steam Air Heater from Marine Steam Propulsion Plant, Energies 2018, 11 (11), 3019, (doi:10.3390/en11113019)

[15] Noroozian, A., Mohammadi, A., Bidi, M., Ahmadi, M. H.: Energy, exergy and economic analyses of a novel system to recover waste heat and water in steam power plants, Energy Conversion and Management 144, p. 351–360, 2017. (doi:10.1016/j.enconman.2017.04.067)

[16] Mrzljak, V., Poljak, I., Medica-Viola, V.: Energy and Exergy Efficiency Analysis of Sealing Steam Condenser in Propulsion System of LNG Carrier, International Journal of Maritime Science & Technology "Our Sea" 64 (1), p. 20-25, 2017. (doi:10.17818/NM/2017/1.4)

[17] Mrzljak, V., Poljak, I., Žarković, B.: Exergy Analysis of Steam Pressure Reduction Valve in Marine Propulsion Plant on Conventional LNG Carrier, International Journal of Maritime Science & Technology "Our Sea" 65(1), p. 24-31, 2018. (doi:10.17818/NM/2018/1.4)

[18] Ahmadi, G., Toghraie, D., Azimian, A., Ali Akbari, O.: Evaluation of synchronous execution of full repowering and solar assisting in a 200 MW steam power plant, a case study, Applied Thermal Engineering, 112, p. 111–123, 2017. (doi:10.1016/j.applthermaleng.2016.10.083)

[19] Tan, H., Shan, S., Nie, Y., Zhao, Q.: A new boil-off gas re-liquefaction system for LNG carriers based on dual mixed refrigerant cycle, Cryogenics 92, p. 84–92, 2018. (doi:10.1016/j.cryogenics.2018.04.009)

[20] Mrzljak, V., Senčić, T., Žarković, B.: Turbogenerator Steam Turbine Variation in Developed Power: Analysis of Exergy Efficiency and Exergy Destruction Change, Modelling and Simulation in Engineering 2018. (doi:10.1155/2018/2945325)

[21] Lemmon, E. W., Huber, M. L., McLinden, M. O.: NIST Reference Fluid Thermodynamic and Transport Properties-REFPROP, Version 9.0, User's Guide, Colorado, 2010.

ASSESS THE RISK OF SHIPPING ACCIDENTS IN THE BLACK SEA THAT MAY BE BASED ON STRUCTURAL DAMAGE

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Summary

This study is designed to create a safer environment for the marine ecosystem and for the safety and health of crew members of vessels which are operating in the Black Sea. The need to assess the risks of structural fatigue arises from the fact that various ships that have been involved in serious maritime incidents have not resisted from a structural point of view, the ships breaking even in two pieces. In this respect, the risks that may occur due to the excitement of the natural environment to which the ship is subjected under real conditions of use from a long-term perspective can be calculated. To determine the natural factors that influence the ship in a real scenario and to perform a precise fatigue calculation the sea state conditions simulated by the SWAN (Simulating WAves Nearshore) model in the Black Sea basin are used. This wave model was forced with wind fields provided by the U.S. National Centers for Environmental Prediction, Climate Forecast System Reanalysis (NCEP-CFSR). Twenty-one serious shipwrecks occurred from 2001 to 2017, of which 5 were in 2017. Some of the ships have been shipwrecked or submerged due to structural damages caused by extreme storms. It can be mentioned here that the average age of the vessels involved has been over 37 years. This leads to an interest in investigating the exact causes of the occurrence of at least one percent of this series of tragic events in the studied geographic area.

Keywords: Black Sea, cargo ships, fatigue, structural resistance

1. INTRODUCTION

Due to the phenomenon of globalization, the opening of international markets after the 1990s to the countries of the former communist bloc, the increase of the individual requirements for the daily lifestyle needs, the volumes of goods transported in general increased [1]. Due to the fact that water transport is one of the most viable forms of transport of goods in very large quantities, a large number of ships have appeared to fill this need and the naval industry has been mainly developed to meet the demands of globalization [2]. This is desirable for local communities because this phenomenon attracts from the financial point of view, economic growth in the areas in which this activity develops.

In the context of an increase in the number of vessels that are part of the global fleet, for example in the period 1997-2011, some 17000 new vessels have appeared on the market [3]. A significant volume of ships is operating in the Black Sea geographic area, but unfortunately, not all of these ships are new. Moreover, a large percentage of them are aging ships, thus increasing the average age in certain maritime shipping areas around the world, and even for the studied area [3]. As every action brings about a reaction, this economic development is accompanied by a series of problems related to the context of environmental protection, in this case increasing the risk of pollution through all forms of water transport activity. However, this paper aims to study the context in which a series of serious shipwrecks occurred in the Black Sea, which resulted in losses of human lives and/or the pollution of the Black Sea environment with oil products (e.g. fuel, oils, etc) [4][5].

Safety at sea is the aim of interest of this paper due to the major social and economic implications of the end result of such a tragic event. This work was designed to show that some ships, similar to ships involved in naval accidents, operate in high risk conditions for the crews and for the marine environment areas where it sails [6][7]. Given this very high risk, steps should be taken to ensure that these ships, whose structural safety features are exceeded, will be withdrawn from their activities by means of legal actions relating to maritime safety regulations in the first place, and on the other hand using pollution criteria and economic implication of the remedial actions of the effects of a potential accident.

2. MATERIALS AND METHODS

2.1. Working hypotheses

According to a previous survey study [8] covering the period 2001-2017, in the Black Sea have been 21 serious naval incidents that have resulted in foundering, sinking or loss of propulsion of the vessels concerned. The geographical distribution of the events on the map is represented in Figure 1, where it can be noticed that all events have been occurred in the proximity of the Black Sea coastline (especially the areas with the highest density of incidents). Due to the high density of vessels in the Black Sea the ships have to follow some constraints, generally in the areas located in the vicinity of the harbours. The most intensely circulated Black Sea stretches are represented primarily by the exit-entrance to/from the Bosphorus Strait and the second place is considered as the crossing through the Kerch Strait. The Bosphorus Strait is the way the Black Sea with the Marmara Sea, then the Mediterranean Sea and, in the last instance, the Planetary Ocean. The Kerch Strait represents the connection between the Sea of Azov and the Black Sea.

Figure 1 Geographical layout of naval accidents in the Black Sea, 2001-2017

Source: Data processed from [8]

In the same study mentioned above [8], it was observed that the cargo ship is the type of ship with a higher rate of incidence in shipwrecks classified as serious [3]. According to Figure 2, 81% of the ships involved in the period 2001-2017 in serious shipwrecks are Cargo vessels. The Cargo ship is a vessel dedicated to commercial cargo transport operations, both containerized, packaged but also in bulk, that can also accommodate on board oversized equipment such as: agricultural machinery, industrial equipment, etc. Usually, they are dedicated to the short distance transport of goods between nearby ports. Nowadays, the manufacturing technology is by welding, both the stiffeners and the sheet shell.

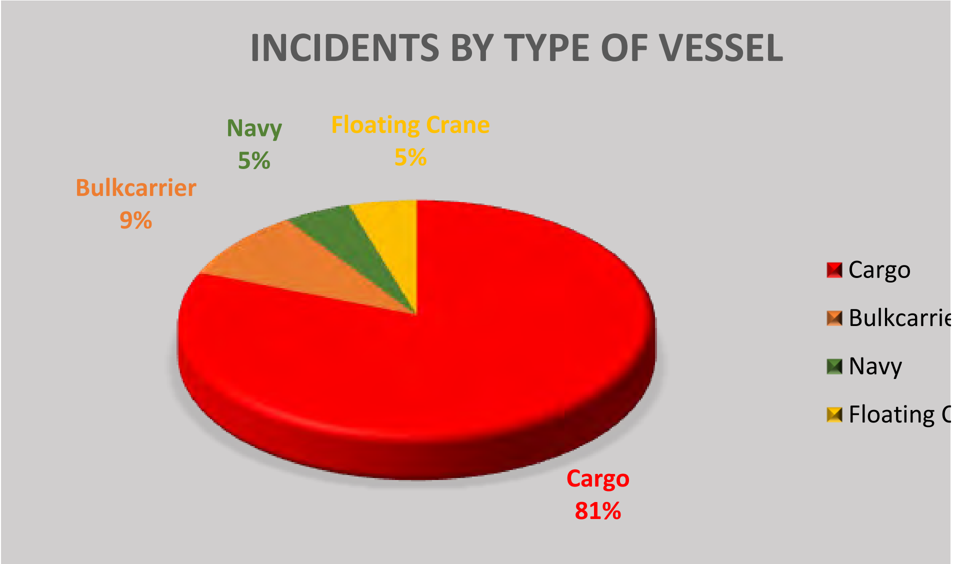

Figure 2 Percentages by type of vessels involved in shipping accidents in the Black Sea, 2001-2017

Source: Data processed from [8]

The identified vessels were gathered in Table 1, where 17 Cargo ships suffered one of the following three incidents: shipwreck, sinking, or a propulsion problem due to the engine. As a result of this operation, the ship identification index in this paper, the name of the vessels, the type of the incident, the year of the accident (the exact date exists as an entry date but could not be presented due to the lack of space in the table), the year of shipbuilding, the flag under which the ships had their flag pavilion, the main dimensions (Length x Beam) and the type of ship which is Cargo vessel in this case, for this study. After the arithmetic mediation of the general construction dimensions (length and beam) of the 16 ships to which these data are known, the following features resulted: Length = 103.43 m, Beam = 13 m.

Table 1 Cargo vessels involved in naval accidents in Black Sea 2001-2017

ID	Vessel	Incident	Incident year	Year Built	Flag	LxB	Type
1	Geroi Arsenala	Sank	2017	1980	Panama	114x13	Cargo
2	Anda	Sank	2017	1981	Togo	95x13	Cargo
3	Leonardo	Sank	2017	1975	Mongolia	114x13	Cargo
4	Bilal Bal	Foundered	2017	1974	Turkey	78x13	Cargo
5	Fom	Engine fail	2016	1981	Panama	73x11	Cargo
6	Gulf Rio	Foundered	2015	1984	Kitts Nevis	89x12	Cargo
7	Fort Azov	Foundered	2015	1970	Kitts Nevis	114x13	Cargo
8	Akel	Sank	2015	1967	Liberia	58x9	Cargo
9	Elga-1	Sank	2014	1991	Russia	139x16	Cargo
10	Nikolay Bauman	Foundered	2013	1973	Moldova	113x13	Cargo
11	Vera	Sank	2012	1977	Cambodia	113x13	Cargo
12	Karam 1	Foundered	2010	1977	Sierra Leone	93x13	Cargo
13	Volgoneft-139	Sank	2007	1978	Russia	132x16	Cargo
14	Volnogorsk	Sank	2007	1970	Russia	123x14	Cargo
15	Nakhitchevan	Sank	2007	1966	Russia	103x12	Cargo
16	Kovel	Sank	2007	1958	Russia	104x14	Cargo
17	Hash Izmail	Sank	2007	-	Georgia	-	Cargo

Source: Data processed from [8]

The data in Table 1 were processed in order to identify a number of features of the identified fleet, which are the subjects of this analysis. A possible causality noted in other studies, independent of this work, is the country of registration of ships involved in such accidents. Figure 3 shows that some pavilions under which ships operate pose a greater risk of accident in the event of such incidents. This leads to the idea that some pavilions are suspicious of flagging rules for these ships. So, in the present study, the greatest risk of accidents for Cargo ships is Russia's flag, followed by Kitts Nevis and Panama.

Figure 4 highlights the fact that a significant percentage of ships pose structural risks because 65% of the vessels have sunk. Only 6%, meaning a single ship with technical problems in terms of propulsion, due to a motor malfunction that could have resulted in a shipwreck, but from the information identified the ship was rescued from the shipwreck in the last moment. A series of ships, amounting to 29%, which presents a very low structural risk, because the causes of a shipwreck are usually of a bad structural behaviour.

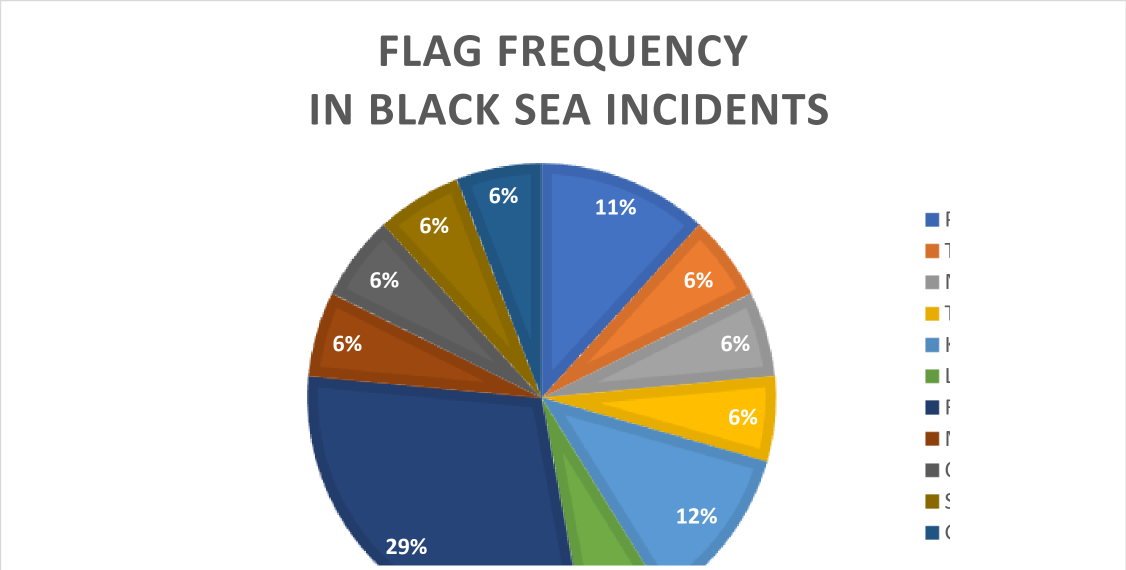

Figure 3 The incidence of the Black Sea naval accidents according to the flag, 2001-2017

Source: Original

A real problem is identified in Figure 5, is that the age of these ships far exceeds the period of activity for which these vessels were originally designed. The activity period provided in the calculations when designing a ship of this type is generally 20, maximum of 25 years. As we can observe in the case of these incidents, the operating time of these ships exceeds in some cases twice the permissibility of operability thought out of the concepts and basic design phases.

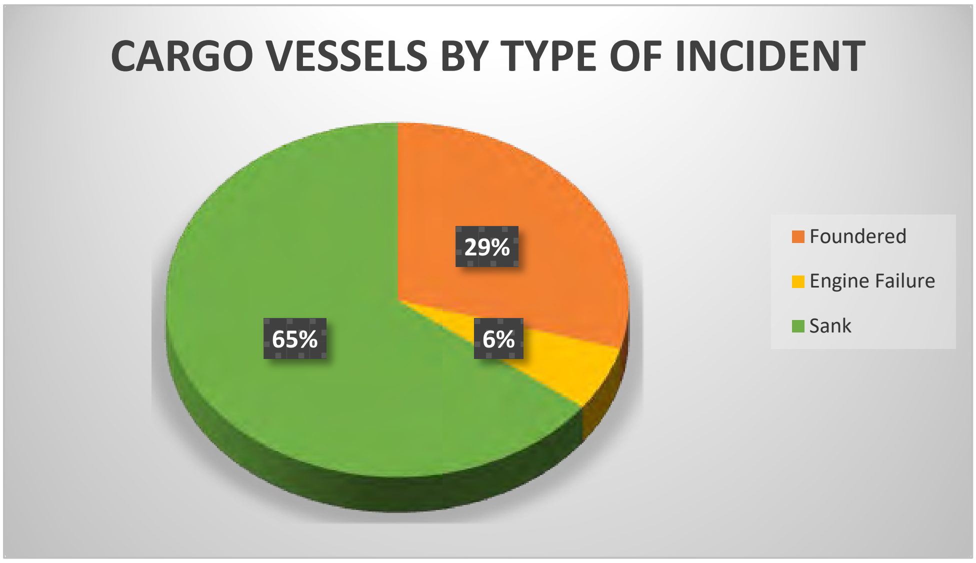

Figure 4 Graphic representation according to the type of shipwrecks in the Black Sea, 2001-2017

Source: Original

Referring to the same information as shown in Table 1 through Figure 5, there are numerous working hypotheses for this research, namely:

- Most vessels involved in these shipwrecks were built between 1975 and 1985.
- The history of the ship was not taken into account due to lack of information on: repairs, corrosion, possible shell or even structural replacements.
- We have not been able to find information on the history of voyages, reports from the classification societies.
- There is no Ultrasound Thickness Measurement (UMT).
- We did not have access to the cargo shipload from the moment of when the accident.

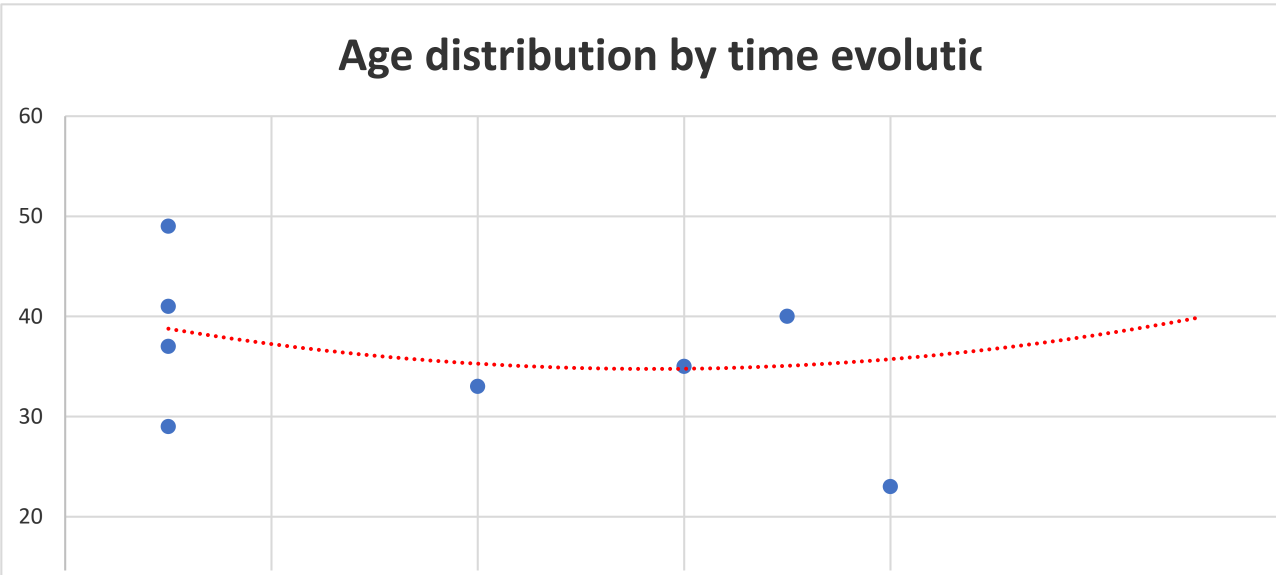

Figure 5 The evolution in time of the age of ships involved in naval accidents in the Black Sea, 2001-2017

Source: Original

Taking into account all the data presented above, and also the lack of multiple information absolutely necessary for the calculation of structural strength of the ship's body involved in serious shipwrecks in the geographical area of the Black Sea, for the period 2001-2017 (vessels that were entered in the Table 1), it was decided to carry out a simplified analysis of the lifetime resistance of the beam gauge, at the expense of a finite element analysis (FEM) analysis. This simplified method treats the structural causes that can lead to structural collapse (bending, shear and ultimate strength) it is presented in chapter "2.2. Methods" and it is using calculation models for the above-mentioned characteristics of the ship-beam.

2.2. Methods

In the initial phase, the general characteristics of the ship representing the cargo ship series as outlined in Table 1 were identified. As a result, a Cargo ship built between 1975-1985, having a length of 103.43 m and a beam of 13m. A vessel with similar features was identified and designed and built during this period. The identified ship was designed under the RNR classification society (Romanian Naval Register, which currently does not exist), so the information found was one without the aid of computer assisted design. The documents used as inputs for this work have been done in a classic paper on monolith paper using writing and hand drawing, which can lead to minor interpretations of the original information.

The identified vessel has the following characteristics, Cargo 5000 Tdw, maximum length 101.5 m, beam 16.4 m, draft 7m, speed 14 knots. Sensitively close characteristics can be observed, which confirmed the possibility of validating the working hypothesis involving a series of operations that will be presented in the following paragraphs.

After the identification of the working hypotheses and the validation of the vessel model identified for the analysis of the strength of the beam-vessel body, the modeling of the cross section was made. This was done in the MARS 2000 software [9], a program developed by the Bureau Veritas Marine Classification Society. Modeling of the master torque was done by reproducing the scantling elements found in the ship's documentation, designed in 1980, under the rules of the Romanian Naval Register (RNR), for testing the section of the ship-beam on the sagging and hogging phenomena. These two cases represent the most unfavorable two loading conditions of the ship-beam because they produce moments and wave-cutting forces with impressive values. Also in view of structural strength verification, the ship was also tested for the criterion of structural collapse.

The Mars 2000 [10] software uses input data, which is distributed in two modules, as is presented in Figure 6. The first module is BASIC SHIP DATA where the ship's preliminary design features have been introduced: project name, material standard, vessel usage factor, ship type, navigation area, perpendicular length, maximum beam, block coefficient, speed operating height, construction height, draft, conditions for hogging and sagging, the type of steel used for various areas of the ship, framing distance.

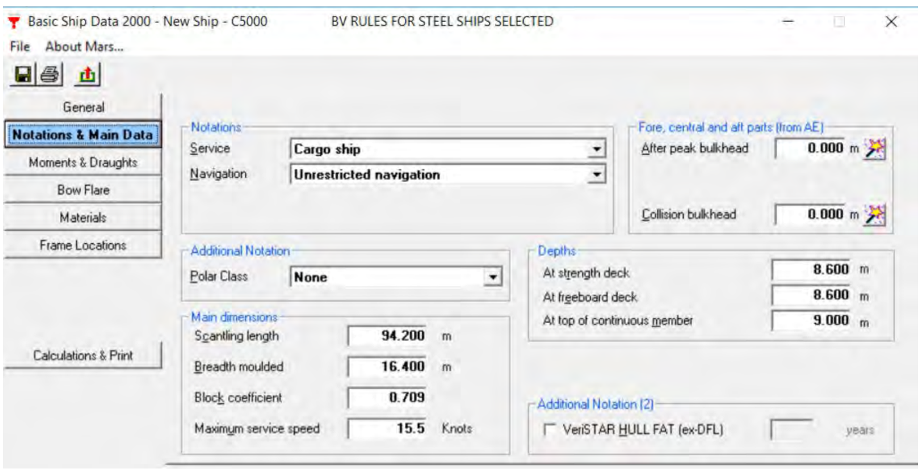

Figure 6 Basic Data of Cargo Vessel used to run in computer application Mars 2000

Source: Original

We take the assumption that the ship was normally loaded, according to the commander's Cargo loading manual. The event was not influenced by any damage that would directly affect the ship's trim. The hypothesis also asserts that cargo holds have not been flooded with water and the ship's commander has not mistakenly operated the ship during the march. So the reason for the collapse would be "exclusively structural", the resistance of the ship beam, corroborated with the advanced corrosion stage.

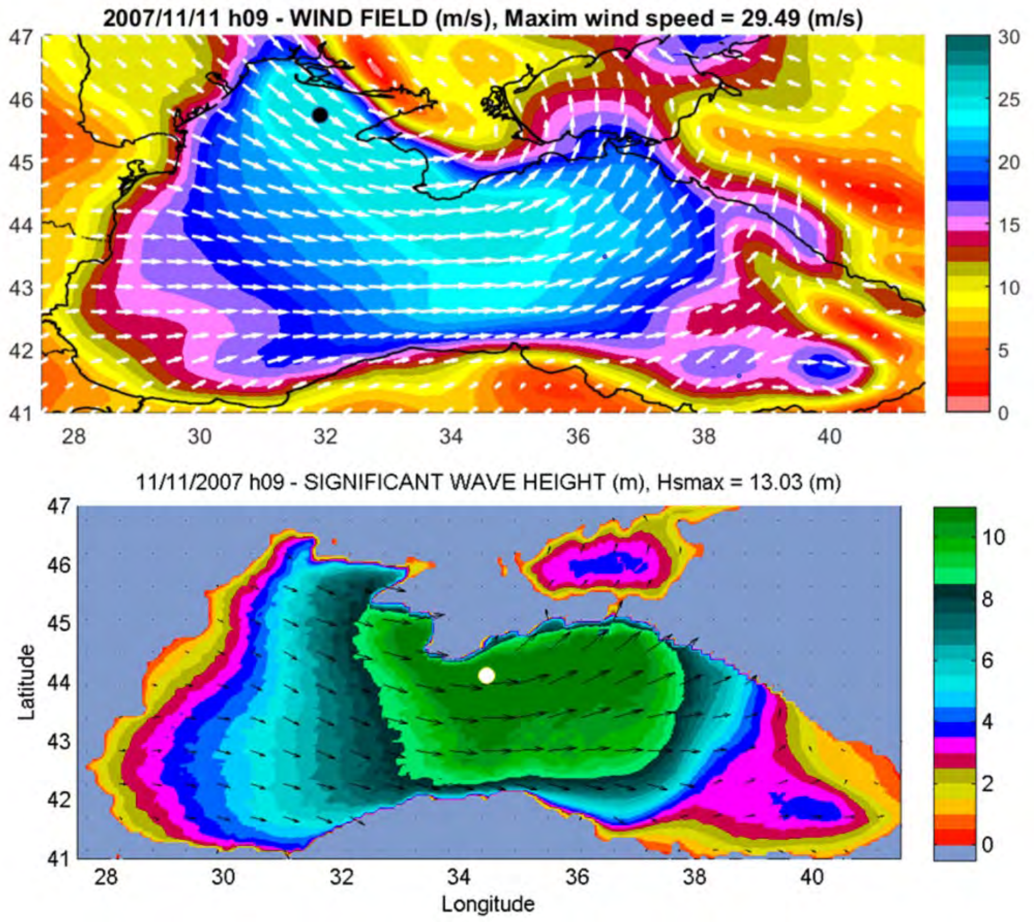

Figure 7 Wind speed and wave height on 11.11.2007 in Black Sea

Source: Original

In order to select one of the „Navigation" criteria the parameters for wave and wind, in Figure 7, were extracted from the sea state conditions over a 30-year period (1987-2016) which were simulated with the SWAN (Simulating WAves Nearshore [11]) model. To drive the wave model the NCEP wind fields were used. The computational domain of the SWAN model is a regular grid with the spatial resolution of 0.08 degrees in both directions (latitude/longitude). The wave model settings, inputs and physics are those used in previous studies performed in the Black Sea area [12-15]. The SWAN model results were validated against in-situ and satellite measurements, while the accuracy of the results was evaluated even under storm conditions [14]. It was shown that the simulation results provided in the Black Sea basin by the wave modelling system based on SWAN forced with the NCEP wind fields implemented are reliable. Results of more than 13 m significant wave height and 29 m/s for wind speed it was selected in Mars 2000 the „Unrestricted navigation" because those parameters corespond for a violent storm in Beafourt scale [16] or hurricane class one for accordint to wind speed in Scara Saffir-Simpson scale [17]. The sea state presented in the Figure 9 represent a close to real condition in the Black Sea at the time of 5 ships accidents out of 17 occurred, presented in Table 1.

The second step is to use the actual scantling module of the ship, reproducing the section faithful to the midship section. In the first phase the nodes for the sheet tables were determined, there are presented in Figure 8, then the thicknesses were added for them, in the second phase the longitudinal and transverse stiffners elements were introduced in order to stiffen the ship-beam [18].

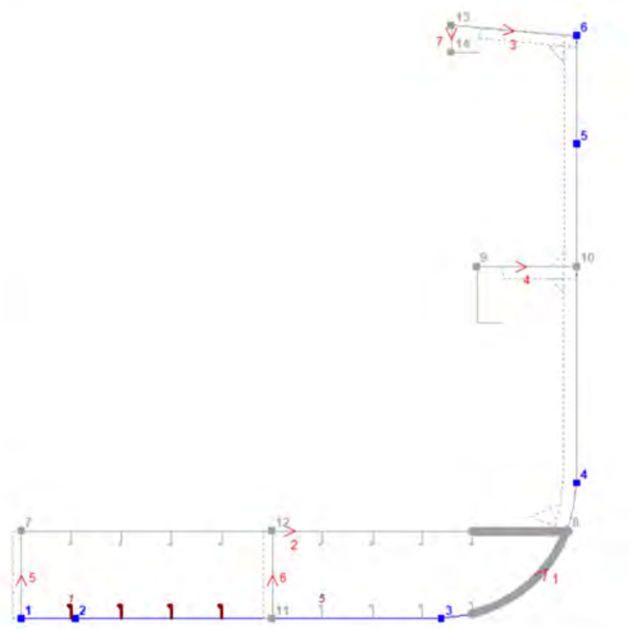

Figure 8 Scantling of a Cargo Vessel designed in '70 to '80

Source: Original

The Mars 2000 application has implemented a calculation algorithm for structural collapse developed in collaboration with the University of Szczecin, Poland [10]. The results of this calculation are based on formulas that meet the class requirements requested by Bureau Veritas and the IACS CSR (Common Structural Rules) [19]. To drive the results as close as possible to the reality, the section was run twice, the first time to determine the effects of corrosion after a period of use of the 25-year vessel. Thus, we identified that in the area of the cargo rooms, the cover sheets (represented by the program with the red color) lost from the thickness by corrosion around 1 mm. The bottom and the upper area (top tank) of the ballast tank with the extension of the bilge radius showed a corrosion loss of thickness around 1, 5 mm and it was represented in green. The most affected corrosion area, as estimated by the Mars 2000 program, is represented with yellow color, given by the sum of the stiffner elements inside the ballast tank.

Figure 9 Corrosion margin of the ship in 25 years of activity

Source: Original

By applying the second time of the Mars 2000 software algorithm, the thickness differences presented in Table 2 result, according with Figure 9. The action of corrosion appears [20] to be quite dramatic even though the difference between the initial values did not seem to result in the significant percentages as highlighted on line 5 of Table 2.

Table 2 Action of corrosion on the structural elements of the Cargo vessel (25 years, 50 years)

Area	Decks	Keel	Bottom	Bilge	Side	Sheer str.	C. girder	L. girder
Initial design (mm)	20	15	12	13	12	17	13	11
25 years (mm)	19	13.5	10.5	11.5	11	16	11	9
50 years (mm)	18	12	9	10	10	15	9	7.2
% (I design - 50 y)	10%	20%	25%	23.08%	16.67%	11.76%	30.77%	34.55%

The values in Table 2 are theoretical and represent the most unfavourable calculation value considering corrosion models adopted by naval classification societies, based on empirical methods but also theoretically validated. These hypotheses only supplement the impact of a uniform corrosion applied globally to this ship, but in real cases, corrosion may have a different run in time and space, which in a definite way depends on how the ship is used, if and how its maintenance and repairs were done. It is necessary to take into account the age of these ships, the way ships were operated and maintained. All those factors had a colossal role in the development of corrosion on sheet metal surfaces and structural elements. In final it results an effect in the ship-beam behaviour on waves in the real state of the sea.

3. RESULTS AND DISCUSSIONS

From the resulting information, following the algorithm for calculating the structural collapse in the application developed by Bureau Veritas, we can identify acceptable values for the Hogging effect for the 25-year designed vessel (N25, H25). Note "N" is used to represent the situation where the ship is in the case of navigation and 25 means the period of 25 years of operation. Note "H" is use when the calculation is made for the ship in calm water, in the port. For the favourable case, where the sea condition is similar to port conditions, the Hogging value does not exceed 50% of the maximum admissible limit for both the 25-year hypothesis and the second hypothesis used in the study.

The ultimate strength represents the response to combined loads which are depending of a diversity of influencing extern factors that involves: geometric shape, material characteristics with its physical properties, building process related imperfections such as initial deflections and residual stresses, service period related to degradation issues such as corrosion and ship and environmental load characteristics or cargo loading arrangement and distribution on board of the ship.

The variable Mu represent the vertical hull girder ultimate bending capacity, in kN.m, and from it using a coefficient factor it is derived the vertical bending moment. Mars 2000 software use a coefficient factor close to 0.95. The message from the right-down corner of Figure 10: "The ultimate bending moment capacity is not a rule requirement" result from the applications of the rule which appear in the Classification Societies Regulations:

- ships need to be longer than 150m.
- ships with unrestricted navigation.
- ships with single deck.

There are two main methods available for determination of ultimate strength of hull girder:

- Nonlinear Finite Element (FE) Method;
- Structural Unit Idealization Method.

In this study it was used the second one, the simplified method, due to the hypothesis that overall ship structure may be considered as a girder to determine the overall loading effects [21].

Table 3 Ultimate strength check for 25- and 50-years Cargo vessel in operation

Condition	Bending moment (kN.m)	Mu	Ultimate	Applied	%
N25	Hogging	472 328	449 579	318 152	70.77
	Sagging	-319 381	-303 999	-323 466	106.4
H25	Hogging	472 328	449 579	217 211	48.31
	Sagging	-319 381	-303 999	-219 743	72.28
N50	Hogging	435 413	414 442	318 152	76.77
	Sagging	-296 841	-282 544	-323 466	114.48
H50	Hogging	435 413	414 442	205 221	49.52
	Sagging	-296 841	-282 544	-207 752	73.53

For the less favourable case, when the ship is in the real sea state conditions and under the wave action, the hogging effect does not exceed 77% of the maximum accepted value for such cases. The curve in Figure 10, in the upper right-hand side, is representing the influence of the hogging effect on the ship beam when calculating for the second hypothesis, for the 50 years.

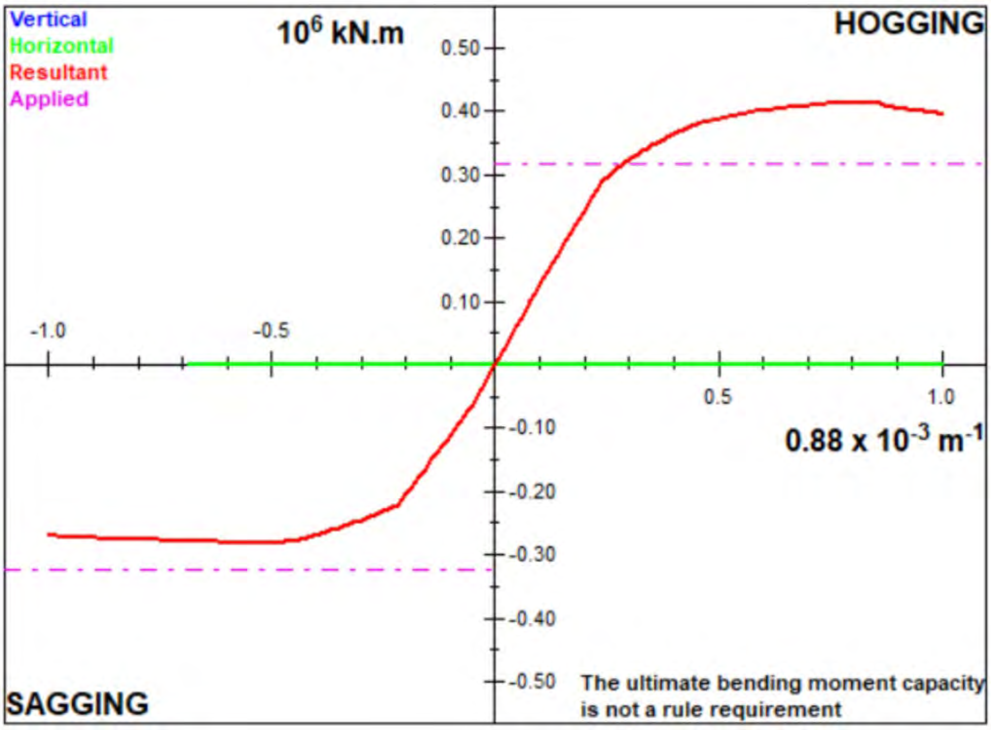

Figure 10 Hogging and Sagging evolution curves for a 50 years Cargo Vessel old

Source: Original

In the case of the sagging effect (Figure 10 and 11) in the H port harbor, the values are up to 75% of the maximum admissible value for this case. Under the most unfavourable conditions, for the case „N" of navigation under the influence of the wave action, the calculated values exceed the limit accepted by the classification societies. Calculating this value for the 25-year period, the limit is exceeded by 6.4%. This confirms that the rules have changed since the 1980s till January 2019, the last update of Mars 2000. A ship designed during the study period 1975-1985, theoretically no longer meets the current requirements of structural strength. From the resulting values for the case when the ship is operated for 50 years, the sagging criterion exceeds the permissible limit by about 15%. A 15% above the permissible limit is a significant value, resulting in the hypothesis studied only by correcting the uniform and general corrosion criteria. On the other hand, there are other factors that aggravate the situation: local corrosion, local fatigue of the structural elements, the possibility of certain steel zones coming out of the elastic deformation area towards the plastic deformation area [22], etc.

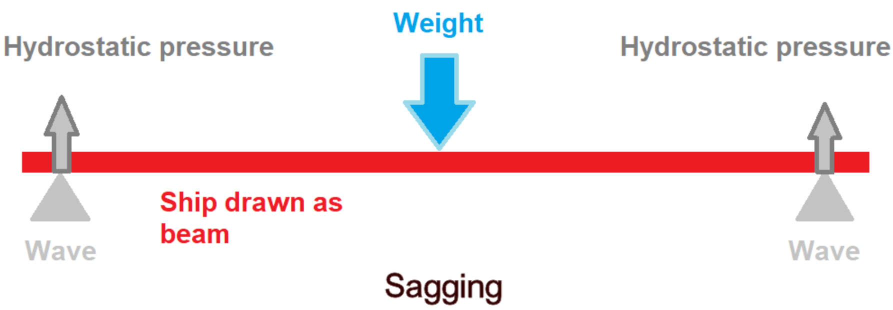

Figure 11 Representation of Sagging effect related to ship drawn as a girder

Source: Original

Another criterion that the ship requires major improvements to the structural strength [23] is given by the necessity, that software shows it in the direction of changing the thicknesses of tables. For example, in the case of tank top area of the double bottom ballast water tank (steel plate "2" shown in Figure 12), the Mars 2000 recommendation is to change the table thickness from 12.5 mm to 88.5 mm thickness. A similar situation we found in the structure of the open deck (steel plate "3" shown in Figure 12), where Mars 2000 software requires a thickening of the board by increasing the thickness of the table sheet approximately 22 mm. Another area with a similar issue, claimed by the software is the side shell, it corresponds also with the graphical representation as a orange circle in Figure 12, where it recommends doubling the thickness of the table. In the last situation the torsion moments located in the shell area are graphical represented in figure bellow.

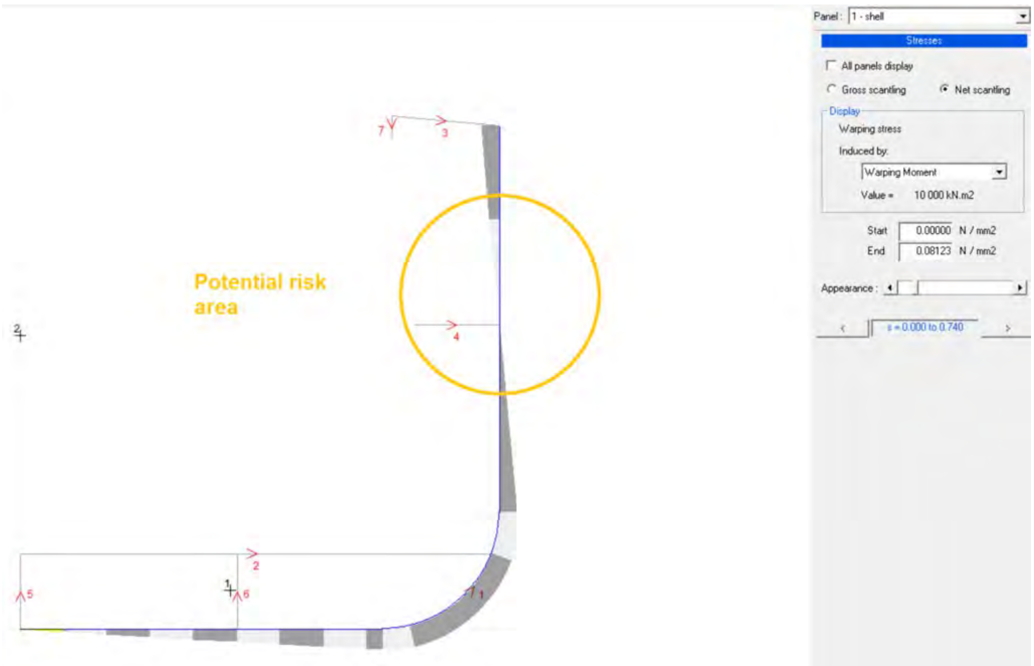

Figure 12 Warping Moment of a 50 years Cargo Vessel old

Source: Original

The occurrence of the torque shown in Figure 12 results largely from the use of a simple scantling system in the shell area. The transverse framing system used for these ships designed and built in the 70's and 80's was a technically easy-to-use as technical solution. Due to the aforementioned criterion, but also because it is a slightly cheaper solution both at the construction stage of these ships and during their exploitation by the shipowners. It is cheaper due to the use of fewer materials and because it reduces the cost of the manhour work, and during the exploitation period it results in a saving of money in view of the fact that the ship is easier, therefore lower fuel consumption plus the possibility of higher load of the cargo. This issue was further solved by applying the IACS (Common Structural Rules) CSR rules [19], [20], using double-sided shell and a mixed framing system.

4. CONCLUSIONS

It is a fact that the shipowners do not want to invest in this old ships which were the subject of this study, from the financial perspective. This kind of approach represent the problem that make worst this situation. Shipowners let these ships to waste and get into a worst state in order to get the bigger profits. This context makes the existing situation worsen continuously every day. The fact that they do not want to invest financial capital to improve them from the structural point of view increases the risks to both the crew lives of these ships and the risks of accidents resulting in final pollution of different types. At the same time, they do not want to scrap these ships, as would normally be done with ships of this age.

The technical conditions are given by the fact that the ships were built under a set of rules, which concern the structural strength with a great deal overtaken. Ships currently built for the same purpose do not pose similar risks due to the fact that they have been improved compared to ships in the study because of implementation of mixed framing the shell side area. In many cases, the solution for the use of double walls for the shell has also been adopted, which gives a higher resistance to torsional moments in the vulnerable zone shown in Figure 12.

It is also clear that structural resistance is impaired over time, and the case presented for calculating the sagging effect values only takes into account a different factor for the case when the ship is operating for 25 years over the period of the 25 initials for which the ship was designed.

It is recommended that a feasibility study be carried out for ships over 5 to 5 years in order to be able to carry out ultrasonic measurements of the thicknesses of the sheets and stiffeners at each mandatory docking. This study is intended to provide a guarantee that the ship can operate safely for a period of 5 years until the next mandatory docking.

It is necessary to implement, through the IMO (International Maritime Organization), a system for monitoring, controlling and verifying the conditions under which ships are allowed to use, from flag states. This is a necessity since some flag state offer certifications to ships that pose a high risk of catastrophes resulting in the loss of human lives but also the pollution of seas and oceans with different types of polluted agents.

As future research directions, it is necessary to assess the stability of the ship in the condition of the state of the sea from the moment of the accident occurrence, of one or more cases out of a total of 17 presented in table 1. These values can be determined using the SWAN model simulations.

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REFERENCES

[1] Stern, N. The transition in Eastern Europe and the former Soviet Union: some strategic lessons from the experience of 25 countries over six years, Lessons from the Economic Transition pp 35-57, (ISBN: 978-94-011-5368-3), DOI: doi.org/10.1007/978-94-011-5368-3_2.

[2] Corbet, J.J.; Winebrake, J.J. 2008. The impact of globalisation on international maritime transport activity: Past trends and future perspectives

[3] Butt, N.; Johnson, D.; Pike, K.; Pryce-Roberts, N. 2013. 15 Years of Shipping Accidents: A review for WWF, Southampton Solent University, Project Report, Southampton.

[4] Gasparotti, C.; Rusu, E. 2012. Methods for the risk assessment in maritime transportation in the Black Sea basin,Journal of Environmental Protection and Ecology 13(3-A): 1751-1759.

[5] Kostianoy A.G.; Lavrova O.Yu.; Mityagina M.I.; Bocharova T.Yu.; Litovchenko K.Ts.,Lebedev S.A.; Stanichny S.V.; Soloviev D.M.; Sirota A.M.; COMPLEX MONITORING OF OIL POLLUTION IN THE BALTIC, BLACK ANDCASPIAN SEAS, Proceedings of the Envisat Symposium 2007. Montreux. Switzerland. 23-27 April 2007. SP 636.

[6] Zheng, Y.; Talley, W. K.; Jin, D.; Ng, M. Crew injuries in container vessel accidents, Maritime Policy & Management, Volume 43, 2016 - Issue 5, pp 541-551, DOI: 10.1080/03088839.2016.1150610.

[7] Kerch Report, Contribution Agreement No 07.0203/2008/518960/SUB/D2 "Environmental Monitoring for the Black Sea Basin: Monitoring and Information Systems for Reducing Oil Pollution". Accessed online in March 2019: www.blacksea-commission.org/_publ-KerchReport.asp.

[8] Rata, V.; Rusu, L., ASSESSING THE TRAFFIC RISK ALONG THE MAIN BLACK SEA MARITIME ROUTES, Proceedings of International Conference on Traffic and Transport Engineering, Belgrade, Serbia, 27th – 28th September 2018, (ISBN: 978-86-916153-4-5).

[9] MARS 2000 Ship structure calculation software. Accessed online in March 2019: marine-offshore.bureauveritas.com/mars-2000-ship-structure-calculation-software

[10] Soares, C.G.; Parunov, J., Advanced Ship Design for Pollution Prevention, Proceedings of the International Workshop “Advanced Ship Design for Pollution Prevention, Split, Croatia, 23-24 November 2009, (ISBN: 978-0-415-58477-7).

[11] Booij, N.; Ris, R.C.; Holthuijsen, L.H. A third generation wave model for coastal regions. Part 1: Model description and validation. J. Geophys. Res. 1999, 104, 7649–7666.

[12] Rusu, L. Assessment of theWave Energy in the Black Sea Based on a 15-Year Hindcast with Data Assimilation, Energies 2015, 8, 10370–10388.

[13] Rusu, Eugen. Study of the Wave Energy Propagation Patterns in the Western Black Sea. Applied Sciences, 2018, 8, 993.

[14] Rusu, L.; Butunoiu, D.; Rusu, E. Analysis of the Extreme Storm Events in the Black Sea Considering the Results of a Ten-Year Wave Hindcast. J. Environ. Prot. Ecol. 2014, 15, 445–454.

[15] Rusu, L.; Raileanu, A.B.; Onea, F. A Comparative Analysis of the Wind and Wave Climate in the Black Sea Along the Shipping Routes. Water 2018, 10, 924.

[16] Beaufort scale. Accessed online in August 2019: en.wikipedia.org/wiki/Beaufort_scale.

[17] Saffir–Simpson scale. Accessed online in August 2019: en.wikipedia.org/wiki/Saffir–Simpson_scale.

[18] Eyres, D.J.; Bruce, G.J.,17 - Shell plating and framing, Ship Construction (Seventh Edition) 2012, Pages 189-205, DOI: 10.1016/B978-0-08-097239-8.00017-9.

[19] Common Structural Rules for Bulk Carriers and Oil Tankers, Common Structural Rules - 1st January 2019 Issue IACS. Accessed online in March 2019: www.iacs.org.uk.

[20] Hussein, A. W.; Teixeira, A. P.; Soares, C.G., Impact of the new common structural rules on the reliability of a bulk carrier, Advance in Marine Structures- Proceedings of MARSTRUCT 2007, The 1st International Conference on Marine Structures 2007, pp 529-538, Glasgow, United Kingdom, 12 March 2007.

[21] RELIABILITY-BASED PERFORMANCE ASSESSMENT OF DAMAGED SHIPS, SHIP STRUCTURE COMMITTEE 2011, SSC-459

[22] Fricke, W., Fatigue and Fracture of Ship Structures, Marine Ship Structures, (ISBN: 978-1-118-47635-2) DOI: doi.org/10.1002/9781118476406.emoe007.

[23] Prestileo, A.; Rizzuto, E; Teixeira, A. P.; Soares, C.G., Bottom damage scenarios for the hull girder structural assessment, Marine Structures, Volume 33, pp 33-55 2013, DOI: j.marstruc.201304.001.

MARITIME AUTOMATION – THE ROLE OF THE HUMANS IN THE FUTURE?

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Summary

The global maritime trade and logistics are attempted to be all the time more and more effective. At the same time with the growing trade, new technology and automation are developed to progress international logistics and to gain economic advantages. Yet, the variation in the development stage of countries and their developmental priorities have an effect on utilization of new technologies. Advantages of implementing new technologies are generally justified by safety improvements, economic benefits, operational efficiency and reduced labour expenses. In the future, also lack of competent work force may be the reason for investing in automation. However, whichever the reasons are, these changes will cause need for new skills and education for personnel and new working routines both onboard and in shore operations. This paper presents the future visions of gradually changing maritime working environment where increasing technology drives new tasks and functions to be conducted gradually remotely from shore-based centres. The role of humans will be emphasized with stages on shore instead of traditional working onboard the vessels. The paper concentrates also on the challenges of the maritime education and training - how MET institutions will take into account the future demand for the stages of increased automation?

Keywords: maritime automation, human element, maritime education & training

1. INTRODUCTION

Maritime transport is vital to the global economy and growing wellness for the people. The global seaborne trade has reached 10.7 billion tons milestone in 2017 and the development is expected to expand 4 per cent per year in the coming years [1]. The supply of seafarers in 2015 has estimated to be about 1,65 million globally and demand for mariners is still rapidly growing [2]. Shipping industry has a long history with many sided traditions. This form of logistics has developed over the centuries and the nature of work in shipping has changed enormously during these times. The growing maritime trade is operated more and more effectively with growing size of vessels and on the other hand with smaller crews. Players in maritime industry are seeking economic advantages, operational efficiency, safety improvements, environmental benefits and, of course, possibilities to reduce labor costs. Some of the tools to achieve these goals are a new technology and various levels of automation which are used innovatively on marine operations at sea and ashore.

The variable stages of development of countries and consequent of developmental needs have though an influence how new technologies are utilized and what are the priorities with investments in near future. Many countries have already now challenges to encourage young people to seek into maritime professions. Reasons for this are naturally various, but the fact that seafarers are away from their homes a long period of time is certainly one of them.

Human resources are needed until further notice onboard despite of increasing technology and level of automation. It is important that maritime industry has educated and skillful work force for its needs also in the future. On addition to industry, also education and training have developed since early times, blackboards have changed to interactive white boards and in latest cases, seafarers can study flexibly from distant with the help of web-based platforms. Currently, the hot topic is, what are the right directions of the education and training so that future seafarers, shipping companies and all other operators can benefit the highly educated maritime professionals. The industry offers certainly interesting career opportunities for young people and hopefully encourages even more also women to build their careers alongside with men.

2. DEVELOPMENT OF MARITIME INDUSTRY

Currently, the international shipping consists of about 60,000 merchant ships, carrying all kinds of cargo and passengers. This fleet is sailing under flags of over 150 countries and manned by 1,65 million seafarers [3]. Development of global shipping has been enormous which is affected by trend towards globalization of production and markets has brought out immense challenges and influenced production and transportation patterns and requirements. This has brought new challenges also for national governments, especially of developing countries, in the management of their economic and social progress. Logistic chains requirements, such as, goods are delivered just-in-time (JIT), have brought reduced expenses at receivers´ end, when need for using warehouses in optimal cases have ended. In turn, this has enlarged requirements of lower shipment cost and reliability to safeguard the continuous implementation of planned production processes. Among the other, the economies of scale in the vessels size have an influence on transport costs and traders prefer to buy timely, when transport services are fast and possibly wider, instead of paying for inventory holding. The containerization of cargo has helped the logistic to be more fluent and has contributed to need for less storage capacity. [4]

The nature of work in maritime industry is changing due to new technology and increasing level of automation. A quicker flow of information and increased means of communication have made possible the information change between a vessel and shore-based operators. As an example of this, ship management and charterer can give easily instructions to the vessel and the ship master is able to report and inform the vessel status more effectively. This means that the ship master doesn´t have to make all decisions by himself anymore but only those which need immediate actions. [5]

Progress of shipping has continued fast in the area of technology and automation. We have already seen many innovations of automation all around in everyday life, such as drones, cars which are self-driving as well as autonomously operated cargo systems. Now the looks have turned to first vessels which are remotely operated, and level of automation is highly increased. Although we have got first examples of automated solutions, the implementation of new technologies in maritime transport have inclined to proceed relatively slow steps and there are several obstacles which set challenges to the implementation of autonomous technology. Even though economic benefits and business models brought in by new technologies and different degrees of automation, it is often argued that higher expenses at the beginning slows down the willingness to invest into these new innovations- as an example, the expenses of building a vessel with the required technology and redundancies for a remotely controlled action is expected to be higher than a traditional vessel. Also, global infrastructure of shore-side systems for controlling and supervising will demand new structures. A new shore-side support means high investments and is required for maintenance, repairs and jobs, such tasks which seafarers from cost-effective labour supply countries now carry out on traditional ships. [6]

3. AUTONOMOUS SHIPPING

The global regulatory body for shipping - the International Maritime Organization´s (IMO´s) senior technical body, the Maritime Safety Committee (MSC) has agreed a framework for a regulatory scoping exercises, " Maritime Autonomous Surface Ship (MASS)" to find the solutions how to implement autonomous shipping in

IMO instruments. MASS defines a ship which "*to a varying degree, can operate independently of human interaction*". The categories of autonomy in this regulatory exercise are defined as follows:

- Automated processes are used on ship and decision making is supported. Systems and functions are controlled onboard by the ship crews which are sailing with the ship. There are certain operations on the vessel which may be automated.
- Ship is sailing with seafarers onboard, but the vessel is controlled remotely and operated distant from another location.
- Ship is operating without the crew onboard and remotely controlled and operated from another location.
- Ship is operating fully autonomously with the help of operating system which makes decisions and actions by itself.

The scoping exercise will as a first step, to identify current provisions in a list of IMO instruments, (SOLAS, COLREG, Load Lines, STCW, STCW-F, SAR, Tonnage Convention and special trade passenger ship) and determine how they may or may not be feasible to vessels with various levels of autonomy and of they may prevent MASS operations.

Secondly, an analysis will be executed to assess the most appropriate means of addressing MASS operations where the human element, technology and operational elements are taking into consideration. [6]

Lloyd´s Register Classification Society has their descriptions for autonomy levels (AL) which are:

- AL 0 – *Manual- no autonomous function.*

All decision making and operations are performed manually which means that humans are controlling ship´s all actions onboard. System onboard may have a degree of autonomy with "human in the loop".

- AL 1 – *On-ship decision support*.

Human operator is taken care of all actions at the ship level, but a tool for supporting decisions can offer options or have an influence on the chosen actions.

- AL 2 – *On and off-ship decision support*

Human operator is taken care of all actions onboard, but a tool for supporting decisions can offer options or have an influence on the chosen actions. Systems may provide information on or off the ship such as DP capability plots, OEM configuration recommendations or weather routing.

- AL 3 – *'Active' human in the loop*

Humans are supervising decisions and actions at the ship level which are performed autonomously. Human operators have an opportunity to intercede and over-ride the high-impact decisions if needed. Information is gathered from system which are on or off the ship.

- AL 4 – *Human on the loop – operator/supervisory*

Humans are supervising decisions and actions at the ship level which are performed autonomously. Human operators have an opportunity to intercede and over-ride the high-impact decisions if needed.

- AL 5 – *Fully autonomous*

The system is making decisions i.e. impact is at the total ship level and operation is unsupervised or rarely supervised.

- AL 6 – *Fully autonomous*

The system is making decisions i.e. impact is at the total ship level and operation is unsupervised.

When decisions of handover to an AL is made, following recognitions needs to be carry out:

- technical feasibility
- risk level presented by the proposed system compared to the manual system. (Risks can be related to economic, safety or security)
- legal constrains [7]

4. MARITIME EDUCATION

Careers linked to maritime transport are originally developed by on- the- job based learning and then in various extent by shore-based education. During the time the combination of shore-based education and practical onboard training has taken place in countries where transportation via sea is possible. Educational systems differ between the countries and therefore possible career paths in maritime sector are various and sometimes young people may have challenging to become aware of all career options in maritime sector. The International Convention on Standards on Training, Certification and Watchkeeping for Seafarers (STCW) Convention 1978 has controlled internationally the education of seafarers when it entered into force in 1984. The purpose of the Convention was to promote the "safety of life and property at sea and the protection of the maritime environment" by creating in common agreement about seafarers' competencies and certification. Convention has been updated several times due to its limitations and the latest major revision was Manilla amendments in 2010. Both STCW Convention and Code were updated with developments and goal was to enable them to address issues that are expected to arise in the near future. [4] However, the curriculums in maritime education and training (MET) institutions are formed individually in different countries under local jurisdictions. Despite the continuing development of international legislative framework and improvements of seafarer´s education and training, STCW Convention sets the minimum level of standards which are not meeting optimally the demands of the maritime industry. Lately, the attention of maritime sector stakeholders has engaged importance of right skills which should be continuously available for needs of the maritime industry. [5]

According to STCW article IX – Equivalents of STCW Convention, development and implementation of with new contents in teaching is made possible. It states:

" The Convention shall not prevent a national government from retaining or adopting other educational and training arrangements, including those involving sea-going service and shipboard organization especially adapted to technical developments and to special types of ships and trades, provided that the level of sea-going service, knowledge and efficiency as regards navigational and technical handling of ship and cargo ensures a degree of safety at sea and has a preventive effect as regards pollution at least equivalent to the requirements of the Convention"

However, the further education i.e. the master level education for mariners progresses the possibilities to build the career path from sea to shore after the seafaring. Many managerial positions in land-based organization require higher degree and this development of further education for mariners has been one solution for industry´s demand.

"Technological advantages may disrupt labor markets as traditional jobs change and disappear, even as the number of young job-seekers continue to grow. Re-training will be needed at previously unimaginable scales. Education must adapt, from the earliest grades. And the very nature of work will change."

Antònio Guterres, Secretary-General, United Nations [6].

5. MARITIME PROFESSIONALS IN THE FUTURE?

It is said, that technology will create new high-tech jobs. It is still difficult to predict the future and estimate what will be the number of those new vacancies and what are the needed skills in order to successfully work with these new technologies and what are the possibilities to retrain existing work forces to serve the demand of developing maritime industry?

World Maritime University (WMU) and International Transport Worker´s Federation (ITF) published a report "*Transport 2040 – Automation Technology Employment* – The future work" in 2018, where it is estimated that highly automated ships would decrease globally the growth rate in the demand of seafarers. The possible reduction of seafarers would be 22 per cent by 2040. According to this report, the need for new types of workers, such as operators who work remotely, different types of maintenance crews and mobility-as-a service providers will increase. [6]

Infrastructure of shipping and control if the logistics are changing into the direction of more centralized and interconnected operation centres, such as fleet operation and maritime vessel traffic service centres [6]. In the future, the vision is that autonomous ships would be operated remotely from shore-based controlling centres (Shore Control Centre, SCC) and the operator would oversee several ships during his /her watch. Normally, vessels would operate and make decisions autonomously, but in critical situation or in abnormal event, the SCC supervisor could take the complete control of the ship and manoeuvre the vessel remotely. [5] The role of the person who monitors the ships safe operation would be similar to Vessel Traffic Services (VTS) operator role that currently is supporting the safe navigation on coastal areas with the difference that in the future the operator would have possibility to take the full control of the ship.

The maintenance work of the ships is planned and timed so that specialized crews would flexibly offer their services from certain service hubs either by conducting the work remotely via internet connections or shifted to ports where technical servicing is needed. [6]

5.1. The Ship Master

The master of the vessel is in unique position in various ways when he or she is taking care of tasks which are under his / her responsibility. Today, the ship master is working as a representative and an employee who is hired by the ship owner or ship management company. The master of the ship is the highest authority on the vessel and is primarily responsible for the seaworthiness of the ship, safety of human lives, safe carriage of the cargo to addressed destination and protection of the marine environment. Nevertheless, the master´s status has narrowed during the times because of development and changes in shipping environment. However, the final decision-making power belongs to master of the ship even he / she is able to get support and orders from shore side management and charterers easier than before, thanks to modern communicational technology. In the critical situations the ship commander acts and makes the decisions ultimately according to his/her best considerations. This sphere of responsibility is determined in the maritime laws. [11]

The ship master is looking after charterers interests and ensures that there is no delay with cargo operations or during the sea voyage. The future visions seem to be that with assistance of information technology and automation, tasks such that ship master is onboard responsible for, will be done remotely from control centres. Task related to cargo handling would be transferred to local representatives of agents. Many internationals regulations and national laws regulate the ship master´s responsibilities and obligations. The other members of the crew do not play that remarkable role compared to the ship master´s role in respect of legal issues. The future of automated ship doesn´t seem to be from that point of view so complex. [5]

6. CONCLUSION

Maritime Universities are adapting their educational trends towards the future needs of maritime industry. It is vital that maritime industry and MET institutions to co-operate closely and find the understanding how to also support careers of maritime professionals Even though, degree programs in bachelor level are tightly planned according to

STCW requirements, it is important to develop the curriculum so that seafarer education is adapting quickly to the industry´s call.

Certain skills are highlighted for the future maritime professionals. Common belief is that for supporting different levels of autonomy, the deeper understanding of for example on-board systems, humans factor skills, management and decision making skills as well as communication skills are important. [10]

The role of humans in future seafaring will be twofold. The cruise industry is growing fast and there will be more demand for seafarers and personnel in cruise industry. In this business there will be more persons who will spend time in the Oceans - both passengers and crew. When carrying cargo, the situation will probably be different. The need for lowering costs in world trade will in the end lead to fully autonomous seafaring where human´s role is to monitor and control the traffic from distance. This will probably take decades and there will be several stages in development. The change will therefore be both interesting and demanding for maritime education.

REFERENCES

[1] UNCTAD, "Review of maritime transport 2018," United Nations Publications, New York, 2018.

[2] BIMCO, "Bimco Manpower report- The global supply and demand for seafarers in 2015," 2015.

[3] Allianz Global Corporate & Specialty, "Safety and Shipping Review 2019 - An annual review of trends and developments in shipping losses and safety," Allianz Global Corporate & Specialty SE, Munich, 2019.

[4] United Nations cenference on trade and development, "50 Years of Review of Maritime Transport, 1968-2018: Reflecting on the past, exploring the future," United Nations, 2018.

[5] N. Roos, "Autonomous Vessels - A Ship Master´s Status Now and In The Future," in *Book of Proceedings - 8th International Maritime Science Conference April,11th-12th 2019*, Budva, Montenegro, 2019.

[6] World Maritime University, "Transport 2040 - Automation technology employment - the future of work," World Maritime University, Malmö, 2019.

[7] The International Maritime Organization, "Imo takes first steps to address autonomous ships," IMO, 25 5 2018. [Online]. Available: http://www.imo.org/en/mediacentre/pressbriefings/pages/08-msc-99-mass-scoping.aspx. [Accessed 3 6 2019].

[8] Lloyd´s Register, "Cyber-enabled ships - ShipRight procedure - autonomous ships," Lloyd´s Register, 2016.

[9] IMO, "International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)," IMO, [Online]. Available: http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-on-Standards-of-Training,-Certification-and-Watchkeeping-for-Seafarers-(STCW).aspx. [Accessed 20 5 2019].

[10] World Maritime University, "MARTID- Maritime Training Insights Database - 2019 Training Practices Report," WMU, 2019.

[11] N. Roos, "Ship master´s legal position, Aluksen päällikön oikeudellinen asema," Satakunta University of Applied Sciences, Rauma, 2012.

AUTONOMOUS AND REMOTE CONTROLLED VESSELS – HOW WILL THE RISK BE ASSESSED BY HULL UNDERWRITERS?

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Summary

Unmanned ships are vessels, which are capable of controlled movement in the water in the absence of any crew on board. Instead, control is performed essentially in two ways: by remote control or the ship may also be "controlled" autonomously. This involves the ship being pre-programmed before deployment, and thereafter, performing a predetermined nautical course without any human interaction whatsoever. This is the future, which will soon be here. At the moment both IMO Legal committee and Maritime Safety Committee have started their work on reviewing different IMO conventions and the changes needed in them to make remote controlled and autonomous seafaring possible in the near future. This consideration is in close relation to risk assessment insurers and especially liability insurance. Traditionally the P&I insurance covers the dominant part of shipowners´ liability, but there is an element of liability also in hull insurance, for example a part of collision liability is covered by the hull insurer of the vessel. Collision liability, liability for damages on the vessel itself, total loss, general average contributions as well as salvage charges are all risk elements which need to be covered by the hull underwriters also when vessels are remote controlled or autonomous. Several risk factors need to be evaluated when insurance is admitted. Will the absence of the crew diminish or increase the risks for the insurer? The human factor causes 80 % of accidents at sea but will the human factor risk vanish by the introduction of the remote-controlled or autonomous vessels? The remote controller can make human errors if he/she does not have the similar kind of information or even if he/she had the same information available as the crew on board. When discussing the risk assessment connected with autonomous vessels, the human factor element is diminished to situations when the autonomous vessel is "taken over" by an outside controller. In this article the risk assessment problems are divided into two basic situations. Firstly, I will determine the risks on shorter predetermined routes where the vessel is either remotely controlled or autonomous. Both are considerations, which are already under process by Nordic countries´ hull underwriters as the vessels will start operations by 2020 in national traffic. Secondly, I will compare this risk assessment to international traffic and the changes they bring to risk assessment criteria in the future. The economical side of risk assessment is critical for the use of the technology – the investments in technology need to create also other savings than those with diminishing manning cost. Cutting down the risk should also create savings in the insurance cost from the hull insurance. I will analyse if this is achieved by the remote controlled or autonomous vessels.

Keywords: Autonomous vessels, Risk assessment, Marine insurance, Maritime economics, Human factor

1. INTRODUCTION

Remote controlled vessels and autonomous vessels have already been developed for quite some time and technology is moving fast.[1] Legal rules are developed slowly when you compare them to technological development.[2] It is difficult to predict how fast the unmanned and remotely operated vessels will dominate the seas. The average lifetime of vessels is long so in any case the traditional vessels with crew on board will still be used for decades. The rules of law need therefore to be applied to both manned and unmanned vessels for a long time. In any case there will always be vessels which need to have crew on board. As often, law needs to be changed to meet the demands of technology.

The maritime risk is closely related to the liability conventions as in marine insurance even the property insurance has liability elements. Both IMO Legal committee and Maritime Safety Committee have started their work on reviewing different IMO conventions and the changes needed in them, to make remote controlled and autonomous seafaring possible in near future.[3] . IMO has decided to start a scoping exercise to identify current provisions in an agreed list of IMO instruments and assess how they may or may not be applicable to ships with varying degrees of autonomy[4] and/or whether they may preclude MASS operations and after that, an analysis will be conducted to determine the most appropriate way of addressing MASS operations, taking into account, inter alia, the human element, technology and operational factors[5].

The development will be gradual and the first fully automated example from Finland has been conducted with ferries on short distance. This has also raised some differing opinions.[6] In the future, the vision is that autonomous ships would be operated remotely from shore-based controlling centres (Shore Control Centre, SCC) and the operator would oversee several ships during his /her watch. Normally, vessels would operate and make decisions autonomously, but in critical situation or in abnormal event, the SCC supervisor could take the complete control of the ship and manoeuvre the vessel remotely.[7]

The Marine insurance Market needs to develop its rules and practices to meet the autonomous shipping world in near future, as there are already several projects where different levels of autonomy are taking place[8]. The risks have to be determined as the risk division will not be the same as in the times where

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[1] SAFETY AND SHIPPING REVIEW 2019, page 7: *"Progress continues to be made in the area of autonomous shipping, particularly in coastal waters and with smaller vessels and it is anticipated that such developments will improve shipping safety."*

[2] *"Autonomous ships in unchartered waters"*: *"In 2018, the International Maritime Organisation began looking into the need to make amendments to the international legal framework to facilitate autonomous shipping, among other things, with respect to maritime safety, manning and operations. The work is expected to take years."*

[3] IMO Webpages: "*IMO takes first steps to address autonomous ships": "The list of instruments to be covered in the MSC's scoping exercise for MASS includes those covering safety (SOLAS); collision regulations (COLREG); loading and stability (Load Lines); training of seafarers and fishers (STCW, STCW-F); search and rescue (SAR); tonnage measurement (Tonnage Convention); and special trade passenger ship instruments (SPACE STP, STP)."* The Liability Convention and conventions like Salvage Convention however belong to the auspices of the IMO Legal Committee, which will make its own scoping exercise.

[4] The Maritime Safety Committee (MSC) has agreed a framework for a regulatory scoping exercises, "Maritime Autonomous Surface Ship (MASS)" to find the solutions how to implement autonomous shipping in IMO instruments. MASS defines a ship which "*to a varying degree, can operate independently of human interaction*". The categories of autonomy in this regulatory exercise are defined as follows: 1) Automated processes are used on ship and decision making is supported. Systems and functions are controlled onboard by the ship crews which are sailing with the ship. There are certain operations on the vessel which may be automated. 2) Ship is sailing with seafarers onboard, but the vessel is controlled remotely and operated distant from another location. 3) Ship is operating without the crew onboard and remotely controlled and operated from another location. 4) Ship is operating fully autonomously with the help of operating system which makes decisions and actions by itself.

[5] See IMO Webpages: "*IMO takes first steps to address autonomous ships*"

[6] SAFETY AND SHIPPING REVIEW 2019, page 41: *"Ferries may sound like a good place for automation, but I can't think of a worse place. If you take the crew off a ferry you introduce risk," says Captain Andrew Kinsey, Senior Marine Risk Consultant at AGCS. "I am all for automation to support the crew, but it would be foolhardy to remove crew from vessels with passengers.*

[7] See Roos. "Autonomous Vessels - A Ship Master´s Status Now and In The Future," in *Book of Proceedings - 8th International Maritime Science Conference April, 11th-12th 2019*, Budva, Montenegro, 2019.

[8] SAFETY AND SHIPPING REVIEW 2019, page 41: *"In December 2018, Rolls-Royce demonstrated what it claims is the world's first fully autonomous ferry on a trip between Parainen and Nauvo in Finland1. The UK-based engineering group plans to bring self-guided cargo ships to the world's seas by 2025". "Meanwhile, Norwegian shipbuilder VARD2 is currently building a small autonomous electric container vessel for fertilizer company Yara, planned for launch in early 2020 with autonomous operation expected by 2022. China is setting up a 225-square-mile test zone for autonomous ships while a group of Japanese shipping lines have formed a consortium to build remote-control cargo ships by 2025"*

the insurance originates from.[9] The insurance market in shipping is international but insurance conditions are not regulated by conventions, they are more based on a "private law" realized by the markets in co-operation with participants representing different industry stakeholders than law made public bodies. Despite many common issues in these conditions there are also differences.

In this article I will first analyse some of the basic differences which affect the hull insurers´ possibilities to offer insurance for remote controlled or autonomous vessels as well as the flexibility of the markets to offer insurance solutions to this industry. This flexibility is also essential for the economical evaluation and risk assessment. The basic difference is defined as hull insurance based on all risk insurances and named perils insurances. In this respect I will use two most common examples which dominate the markets. Nordic Marine Insurance Plan and the English Hull clauses are used as examples to envisage the differences between these two systems. In the end, their flexibility to meet the client´s demands is analysed.

1.1. Nordic Marine Insurance Plan

Nordic Marine Insurance Plan (later NMIP) can be considered being based on the all risk insurance -principle[10] defined in the clause 2-8, with defined exception to the cover.[11] Compared to the insurances ashore the Marine perils described in the plan cover a broad range of risks. As a starting point they cover any risk which the insured interest is subjected to like fire, collision, grounding, theft, requisition, etc. In English terminology this kind of insurance cover is called "all risks" insurance.[12] Hull insurance in the Nordic Marine insurance is based on the all risks -principle with exceptions listed which will not be covered. The most important is war risk, which can also be separately covered by taking out a separate war risk insurance under the Plan. If the person effecting the insurance has also obtained such cover, there will be relatively few caps in the shipowner insurances insofar as the perils are concerned.[13]

In principle the Nordic Marine Insurance Plan seems to suit remote controlled vessels and autonomous shipping as a starting point. It is clear, however, that the rules need adjustment at least regarding the Commentary to explain clearly the rules and exceptions when applied to remote controlled or autonomous vessels. It is possible, in principle, for the person effecting the insurance and for the insurer to assess the Hull insurance risks in general with the NMIP clauses. The Nordic Plan has detailed rules on causation and duty of disclosure as well as highly developed system of safety regulations, unlike the English system.[14] This will be explained below in detail.

1.2. English Marine insurance

The English marine insurance for hulls is based on perils named in the policy. As the insurance covers the named risks, they are not automatically updated to cover the new risks, which arise in maritime adventure. The English law on marine insurance is also heavily based on case law, such as the Marine Insurance Act 1906 made on basis of existing case law. The difficulty with remote controlled and autonomous vessels is clear. The existing clauses with named perils were not made with the kind of problems in mind that can arise with such vessels. It is unclear how they would suit the purpose without changes or additions. Therefore, I will

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[9] *"Autonomous ships in unchartered waters"*: "Although amendments would have to be made, it has been assumed that cover under existing maritime insurances may be extended to autonomous vessels. For insurers, the greatest challenge will probably be to understand and price the risk correctly. While hull and machinery cover is manageable, protection and indemnity insurance cover poses particular challenges. However, insurers are meeting these challenges. Gard is reported to provide cover for the Yara Birkeland and the Shipowners' Club provides an all-risks type liability policy for autonomous vessels."

[10] Falkanger – Bull – Brautaset, page 654: *"Hull insurance can be effected with wide or narrow scope of loss...", "Nonetheless, it is normal to effect hull insurance "on full conditions."*

[11] CEFOR, *Clause 2-8. Perils covered by an insurance against marine perils: "An insurance against marine perils covers all perils to which the interest may be exposed, with the exception of:..."*

[12] Falkanger – Bull – Brautaset, page 627.

[13] Falkanger – Bull – Brautaset, page 628.

[14] Falkanger – Bull – Brautaset, page 637.

base this article on all risks-based conditions and especially Nordic Marine Insurance plan. A specifically problematic area of English marine insurance law is the warranties and especially warranty of seaworthiness, which will be briefly discussed below.

2. COLLISION LIABILITY

Collision damage and collision liability are an essential risk for Hull insurance.[15] Collisions are considered a major issue in relation to remote controlled and autonomous vessels. The collision results for the insured vessel itself are covered by the hull insurers but the final responsible is determined by the rules of Collision Convention, which were established already in 1910. The liability for the collision is considered according to fault.

This is an especially important issue when the ship is operated from distance or when it operates autonomously. Who is liable if the vessel is not able to avoid the collision or even creates the accident and there is no crew on board – or it is operated from a control centre from a distance? The risk needs to be determined and the collision avoidance rules need to be planned carefully. The first autonomous vessels will be in traffic on short coastal distances shortly. Their route can be taken into account by other vessels and their operators. The examples mentioned above from Finland and Norway are ferries with passengers on a predetermined route and a cargo vessel driving a specific 10 kilometre route in a Norwegian fjord between two predetermined harbours. Collision avoidance in these routes is controllable and the risk can be assessed and valued by the insurers.

A more problematic issue will be the traffic when there are vessels moving remotely controlled or autonomously without a predetermined route when the vessel´s route needs to be changed according to the weather and traffic conditions. The law on collision liability is based not only on Collision Convention and Rules of road but also case law, which determines the fault and liabilities of the participating vessels. When the case law is read, it is clear that the legal rules are complex, as the colliding vessel´s actions always need to take into account the actions and faults committed by the other party or several parties. It should not be impossible to "teach" the existing rules to a computer but as collision cases are not similar and the actions of the other party are not predictable, and as long as the humans interfere, this will be a difficult issue. The risk evaluation will be interesting before we have more testing.

To summarise, the human element is involved in most collisions and mistakes are mostly made by humans. If the technology is highly developed, the safety should be increased also in this respect. Human error continues to be the dominant reason for casualties.[16] Even though the technology increases safety in general, trusting technology in human hands also has negative effects.[17] The autonomous vessels are predicted to increase safety in the future.[18] But as the automation does not solve the problems entirely, the

[15] SAFETY AND SHIPPING REVIEW 2019, page 15: *"Analysis of more than 230,000 marine insurance industry claims with a value of €8.8bn ($9.9bn) between July 2013 and July 2018 by AGCS shows that ship sinking/collision incidents are the most expensive cause of loss for insurers, accounting for 16% of the value of all claims – equivalent to €1.39bn/$1.56bn."*

[16] SAFETY AND SHIPPING REVIEW 2019, page 31: *"It is estimated that 75% to 96% of marine accidents can involve human error. Furthermore, AGCS analysis of almost 15,000 marine liability insurance claims between 2011 and 2016 shows human error to be a primary factor in 75% of the value of all claims analysed – equivalent to over $1.6bn of losses. Given the role of human error in so many incidents, the quality of crew and ship owners' overall safety culture are of increasing importance to risk assessment."*

[17] SAFETY AND SHIPPING REVIEW 2019, page 7: *"The growing use of connected technology in the maritime sector is a positive for safety and claims. Electronic navigation tools, ship-to-shore communications and the greater use of sensors have the potential to improve navigation and help avoid incidents. Sensors can also reduce machinery claims through performance monitoring and early intervention and help mitigate cargo losses. Yet, at the same time, accidents continue to happen due to overreliance on technology – even down to crew members being on their phones when a loss event occurs. A generation of seafarers has grown up trusting what they see on a screen but it is crucial that crew continue to have appropriate training and develop a solid understanding of the fundamentals of sound navigation and situational awareness."*

[18] SAFETY AND SHIPPING REVIEW 2019, page 41: *"With widespread use of autonomous ships unlikely to happen on the high seas anytime soon, early examples are likely to be limited to smaller vessels and coastal waters. Autonomous ships are predicted to reduce human error, a major driver of accidents, but crews are likely to have an important role on board vessels for the foreseeable future."*

focus needs to be on the existing issues for long.[19] When we look at the statistics from previous year, we can already see that the number of casualties has decreased. [20] The risk evaluation process assumes that this development to continue in the future. An interesting issue will be whether this trend is expected to continue by the underwriters when remote controlled or autonomous vessels start operation and how the risk is affected in general in a new situation in relation to general traffic.

3. DAMAGE

As the marine perils are covered by the hull insurance, we will concentrate on those when dealing with risk assessment on damage to vessels. The commentary to NMIP describes the marine perils in detail.[21] According to the NMIP weaknesses in the ship and similar "internal perils" are in principle regarded as perils covered by an insurance against marine perils, which basically means that also technological failures and their consequences are covered. Two important exceptions must, however, be noted in relation to damage to the ship.

First, the insurer is not liable for costs incurred in renewing or repairing a part or parts of the hull, machinery or equipment which were in a defective condition as a result of wear and tear, corrosion, rot, inadequate maintenance and the like.[22] This means only that the part or parts which were defective or were not properly maintained, will not be covered but the consequencencial damage resulting from the breakdown or failure will be covered. If we consider this clause in relation to the remote controlled or autonomous vessels and their technological problems, they seem to be quite well protected in case the casualty results from internal failures of for example data or electronical problems.

Secondly, if the damage is a result of error in design or faulty material, the insurer is not liable for the costs of renewing or repairing the part or parts of the hull, machinery or equipment which were not in proper condition, unless the part or parts in question had been approved by the classification society.[23] This rule highligts the role of the classification societies and their approval of technology becomes even more important when the vessels are remote controlled or autonomous. Inadequete maintenance in clause 12-3 will not be an error committed by the crew when there is no crew and maintenance will be taken care of by persons working ashore and by the shipowner´s servants there. An example of inadequete maintenance could be for example lack of updating computer data according to required intervals or lack of updating

[19] SAFETY AND SHIPPING REVIEW 2019, page 7: "*While there will be incidences where technology and automation will remove crew from hazard, innovation should not be driven primarily by efficiency and accounting. As ongoing issues with large container ships and fires and misdeclared cargo show – innovation and technology is not a panacea if the root cause of incidents and losses is not addressed"*

[20] SAFETY AND SHIPPING REVIEW 2019, page 9: "*The database shows 46 total losses of vessels over 100GT during 2018 around the world. This compares with 98 during 2017 – a significant decline of more than 50%. South China, Indochina, Indonesia and Philippines remains the top region for total losses. A quarter (26%) of losses occurred here, although the total of 12 also represents a significant decline (29 in 2017) – the first time the region has seen a fall in losses in four years."*

[21] CEFOR: Commentary to Clause 2-8: *"An insurance against marine perils covers, in the first place, perils of the sea and similar external perils. Perils of the sea mean the perils represented by the forces of nature at sea seen in conjunction with the waters where the ship is sailing. Typical examples of these perils are where the ship runs aground, collides in fog, suffers heavy-weather damage or is broken down by wind and sea and goes down. Other external perils may be earthquakes, volcanic eruptions, lightning, etc.*

Secondly, an insurance against marine perils covers perils in connection with the carriage of goods or other activities in which the ship is engaged. The cargo carried by the ship may threaten its safety; similarly, passenger traffic may entail special elements of perils.

Thirdly, weaknesses in the ship and similar "internal perils" are in principle regarded as perils covered by an insurance against marine perils. However, there are a number of exceptions and modifications here; in hull insurance, Cl. 12-3 and Cl. 12-4 thus constitute a significant curtailment of cover.

Fourthly, injurious acts by third parties will basically be perils that are covered by an insurance against marine perils. These may be collisions, explosions, fire or the like, which arise outside the insured ship, etc. It is irrelevant whether or not the person causing the damage is blameworthy; damage caused intentionally will also be covered. One important type of injurious act by a third party will nevertheless be excluded from the cover against marine perils, viz. interventions etc. by a State power; such acts will instead to a large extent be covered by the war-risk insurance, see Cl. 2-9, sub-clause 1 (b).

Finally, errors or negligence on the part of the assured or his employees will, as a main rule, be covered by an insurance against marine perils. However, there are important limitations to this cover. Most of the rules of this type are compiled in Chapter 3."

[22] CEFOR: *Clause 12-3. Inadequate maintenance, etc.*

[23] CEFOR: *Clause 12-4. Error in design, etc.*

navigation systems, resulting in a failure of the systems. Errors in design and faulty material etc. need to be carefully audited by classification societies when remote or autonomous vessels are being built.

4. TOTAL LOSS AND CONSTRUCTIVE TOTAL LOSS

The assured has a right to total loss compensation in three situations.[24] According to NMIP the assured may claim compensation for a total loss if the vessel is lost without there being any prospect of it being recovered or if the vessel is so badly damaged that it cannot be repaired.[25]The rules also give the insurer a right to salve the vessel at his own cost[26] The assured may claim compensation for a total loss if the conditions for condemnation of the vessel are met.

The conditions for condemnation are met when casualty damage is so extensive that the cost of repairing the vessel will amount to at least 80 % of the insurable value, or of the value of the vessel after repairs if the latter is higher than the insurable value.[27] It is difficult to predict how introduction of remote controlled and autonomous vessels will affect the number of total losses and how the risk on their insurance will be evaluated by the industry. Taking into account the high percentage of casualties where human error has been the cause of these accidents, it should be considered lower when technology is developing. At this point it is up to insurers´ risk assessment which is difficult to predict and relies highly on technological development and experiments made in the specific areas for the testing.

5. SALVAGE

Updates to Salvage convention were considered last in 2012 by CMI but they were then buried by the IWG and international sub-committee in Beijing Conference of CMI. The unmanned vessels were not then discussed at all. Taking up the salvage law will be an issue in the future and it might be necessitated by the unmanned vessels and encouraged by the salvage industry. It was already a topic on the table in the industry supported conferences in 2018 and in the IMO Legal Committee. The IMO Legal Committee will start to review the need for updating the conventions under its auspices[28]. CMI has made some preparatory work which can be used as a starting point.[29]

In NMIP Salvage is covered by the insurance.[30] Vessels which have been abandoned have been salved and therefore autonomous vessels are not a big change in the salvage industry. Vessels and cargo still need to be salved from marine peril and common perils still encounter the vessels at sea - even when vessels sail without a crew. Cases like "*Pergo*" where abandoned vessels have been salved after they have continued their journey on automatic steering after the vessel had been abandoned by her crew, have been salved before. It is therefore no precedent that an "autonomous" vessel is salved, and salvage remuneration is paid for the salvors without whom the vessel would have been lost.

The owner also benefits from salving his own vessel according to the NMIP rules - if the vessel is salvaged by another vessel belonging to the assured, the insurer is liable as if the salvage operation had been

[24] Falkanger – Bull – Brautaset, page 655: *"When the ship is an actual total loss, NP § 11-1; when the shi is a constructive total loss 8condemnation), NP § 11-3; and when the ship is resumed a total loss, NP § 11-7."*
[25] CEFOR: *Clause 11-1. Total loss*
[26] CEFOR: *Clause 11-2. Salvage attempts: " The insurer is entitled to attempt to salvage the vessel at his own expense and risk. The assured shall in that event do his utmost to enable the insurer to carry out the salvage operation.*
If the salvage operation has not been completed within six months from the date the insurer was notified of the casualty, the assured is entitled to claim compensation for a total loss."
[27] CEFOR: *Clause 11-3. Condemnation*
[28] *See "Autonomous ships in unchartered waters"*
[29] See CMI Webpages: *"CMI Spreadsheet on Conventions"* and *CMI Webpages: "CMI International Working Group position paper on unmanned ships and the international regulatory framework"*
[30] CEFOR: *Clause 4-7. Compensation of the costs of measures to avert or minimise loss: "If a casualty threatens to occur or has occurred, the insurer is liable in accordance with the rules in Cl. 4-8 to Cl. 4-12 for the costs of measures taken on account of a peril insured against, provided that the measures were of an extraordinary nature and must be regarded as reasonable."*

carried out by a third party.[31] Remote controlled tugs have also been introduced by some companies and they are under development for commercial purposes. This might also be a possibility for salvage industry, for example for firefighting purposes as the safety of the crew in the salvage tugs is no longer a precondition for actions of the salvor and a necessity.

When asessing risk, the most important feature for the insurer will be how the remote controlled or autonomous vessels are equipped for the purpose to be salved from distress. Standardisation and class requirements for this purpose need to be created together with the salvage industry and if investments in salvage equipment is needed this should be taken into account when the awards are being assessed.[32]

At this point it is difficult to assess if the development will increase the rewards in future and if the number of salvage cases will rise due to increasing autonomy. The amount of rewards will,however, be spread to the industry as a whole so it is highly probable that this needs not to be taken into account when assessing the amount of salvage cases in the future. The risk for the insurer might,however, be worth considering especially in the beginning when it is difficult to determine how the salvage industry will be able to cope with the unmanned vessels and if the development will increase or decrease the amount of the awards.

6. GENERAL AVERAGE

General average has survived on the basis of York- Antwerp Rules for long even through national legislation exists in some countries.[33] In most countries, however, it has been developed on the basis of YAR. YAR 2016 has already been incorporated in the NMIP rules.[34] According to the NMIP: *"The insurer is liable for any general average contribution apportioned on the interest insured. The hull insurer is also liable for general average contributions apportioned on freight or charterparty hire, provided that the assured is also the owner of this interest. The contribution is recoverable in accordance with a general average adjustment, duly drawn up according to applicable rules of law or such terms of contract as must be considered customary in the trade in question. The contribution is recoverable in accordance with the adjustment, even if the contributory value exceeds the insurable value of the interest. The insurer is similarly liable for salvage awards, insofar as they are not recovered in general average*."[35]

In any case it seems clear that GA will continue as a market driven exercise. It seems that the industry developing the autonomous vessels has already considered the technological solutions needed for GA acts and therefore the need for a change is not great and it can be made by supplementing the existing rules for example by GA rules/guidelines for autonomous vessels to be accepted as a part of the cargo solution or carriage contract and approved by the IUMI as representative of the Marine Insurers. As GA rules are maintained by Comité Maritime International (CMI), the changes and supplements are possible without changing any Convention like the case of salvage above. When YAR 2016 rules were drafted the remote controlled vessels and autonomous vessels were not considered an issue still to be regulated differently[36]

7. SAFETY REGULATIONS AND UNSEAWORTHINESS

The Nordic Marine Insurance Plan has a rule that in order to be covered by the Hull insurance (as well as other shipowner's insurances under the Plan) the assured needs to follow the safety regulations. The assured can risk losing his cover in connection with the breach of safety regulations.[37] Safety regulations have been

[31] CEFOR: *Clause 10-11. Liability of the insurer if the vessel is salvaged by the assured*
[32] See for example Reeder on the encouragement principle.
[33] R. R. Cornah, R. C. G. Sarll and J. B. Shead, on the history of general average law.
[34] CEFOR: *Preface*
[35] CEFOR: *Clause 4-8. General average*
[36] the issue was already taken up by the writer in IWG meeting in Istanbul 2015.
[37] Falkanger – Bull – Brautaset, page 637.

described in the clause 3-22 of NMIP.[38] The insurer has a right to inspect the ship when he suspects that safety regulations have not been met.[39] Breach of safety regulation can lead to the insurer not being liable for the casualty if there is a causal connection between the breach of the safety regulation and the casualty and the breach has been culpable.[40]

Before 2007 NMIP contained a separate clause on unseaworthiness. This clause has been abolished as the rules on safety regulations and unseaworthiness more or less covered the same issues and the Norwegian Seaworthiness Act had also been abolished. This was already considered when the plan was modified largely in 1996. This development gives a clear benefit for the owners who have good maintenance systems and follow the safety regulations strictly as in relation to the insurer there are no grey areas when the insurer, despite the fact that the safety regulations have been followed, can claim the ship being unseaworthy. In future relating to remote controlled and autonomous vessels this can give a clear benefit for the NMIP clauses in relation to the other markets where unseaworthiness in relation to these vessels needs to be determined by courts as there is no case law in the field. The safety regulation in this respect is a Nordic solution. As the safety regulations can be described widely, this gives also flexibility for the insurers to meet the demands of the industry in insuring the vessels with different levels of autonomy

The warranty of seaworthiness is one crucial element in English common law marine insurance. The difference between civil and common law marine insurance in respect of warranties is substantial. Warranties in Marine Insurance Act have been under heavy criticism for long. [41] The recent changes in English insurance law did not solve the problem.[42] The Nordic conditions are known in international market as assured friendly especially since (then Norwegian conditions) 1996 and they have been increasing their market share as at the same time the London market has been losing its own.[43]

The Nordic Marine insurance Plan is not based on warranties and the unseaworthiness concept as insurers´ right to deny cover has been erased 2007.[44] This has made the NMIP conditions even more lucrative compared to English Hull Clauses.[45] Compared to the warranty regime they provide a fairer regime for the assured.[46] This will probably be the case also when the remote controlled and autonomous vessels are insured. Comité Maritime International arranged a seminar in London 2018 where the effect of seaworthiness warranty on autonomous vessel was simulated by case example in workshop:[47] The workshop clearly

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[38] CEFOR, Clause 3-22. Safety regulations: *"A safety regulation is a rule concerning measures for the prevention of loss, issued by public authorities, stipulated in the insurance contract, prescribed by the insurer pursuant to the insurance contract, or issued by the classification society. Periodic surveys required by public authorities or the classification society constitute a safety regulation under sub-clause 1. Such surveys shall be carried out before expiry of the prescribed time-limit. When establishing the Safety Management System that is necessary to fulfil the assured's obligation to comply with the International Safety Management Code as adopted by IMO, the assured shall ensure that the system includes instructions and procedures for the use and monitoring of lubricating oil, cooling water and boiler feed water. Cl. 3-25, sub-clause 2, shall not be applied."*

[39] CEFOR, Clause 3-23: *"The insurer has the right at any time during the insurance period to verify that the vessel meets the technical and operational safety requirements that are prescribed by public authorities or by the classification society. If necessary for the purpose of such verification, he may demand a complete or partial discharge of the cargo. If the assured refuses to let the insurer undertake the necessary investigation, the insurer shall subsequently only be liable to the extent that the assured proves that the loss is not attributable to defects in the vessel which the investigation would have revealed. If the investigation is not occasioned by a casualty or similar circumstances covered by the insurance, the insurer shall indemnify the assured for his costs as well as for the loss he suffers as a result of the investigation, unless it becomes apparent that the technical and operational safety requirements have not been met."*

[40]Falkanger – Bull – Brautaset, page 637 and CEFOR, Clause 3-25.

[41] See Huybrechts, Page 354-357.

[42] Arnould, page 980: *"Section 39(5) remains in place in relation to policies to which the new regime of the Insurance Act 2015, applies. Its application is not affected by the 2015 Act"*

[43] Soyer, page 187-188 "*However, the main reason for the London market losing its market share is intense competition coming from other markets, including France, Germany, Switzerland, Italy, Scandinavia and the USA. There are reports suggesting that the norwegian insurance market in particular managed to get a bigger share of the world´s hull business. The success of the norwegian market lies mainly in the fact that it has secceeded in developing strong links with different interests around the world and attracting a great deal of foreing business."*

[44] Falkanger – Bull – Brautaset, page 637.

[45] Soyer, page 188-189: "*without a doubt, the hesitation of the london Market in underwriting insurance for high risks in the early 1990s played a crusial role in the success of the Norwegian market; However, it is submitted that its main advantage was the the assured-friendly legal rules adopted in insurance policies"*

[46] Wilhelmsen – Bull, page 180.

[47] "*THE CHALLENGING CONVERGENCE OF MODERN TECHNOLOGY CYBERCRIME AND MARINE INSURANCE*". London October 9 2018. https://comitemaritime.org/documents-cmi-bmla-london/

demonstrated the problems, which might arise when English Marine Insurance law will be applied to autonomous vessels colliding with conventional vessels.

Identifying cyber exposures and their relation to insurance condition became also evident. [48] Identifying cyber exposures will be critical in the future as it is clear that they threaten the insurance cover of vessels and will be a threat to the future of remote controlled and autonomous vessels´ future.

8. HUMAN ERROR

Human error continues to be the dominant reason for casualties.[49] Even though the technology increases safety in general, trusting technology in human hands also has negative effects.[50]

The autonomous vessels are predicted to increase safety in the future.[51] But the automation does not solve the problems, but the focus needs to be on the existing issues for long.[52] The human error needs to be addressed specially in education also for the seafarers who will need to focus on the remote controlled vessels and autonomous vessels which will be in traffic among traditional vessels.

When technology for remote controlled and autonomous vessels is being developed, much of it will be used also in traditional vessels to make the process of technology economically possible. Already now the amount of crew can be diminished by replacing a part of it with modern technology and sensors. This development in part increases the possibilities for human error in the use of this technology, if the crew is not well-trained to use it and if at the same time the crew costs are lowered.

9. CONCLUSIONS

Insurance conditions are an important element in the competition for market shares. When new technologies are used, there will also be competition in the market for the insurance cover. If we look at the flexibility of the insurance markets and their ability to reform, we can predict how the market shares will develop in near future. The clients will not need to seek insurance solutions far away from where the technology is being developed. Nordic Marine insurance Plan will have a clear benefit as the owners of remote controlled and autonomous vessels start seeking cover in markets. Norway is in the forefront of developing the technologies.[53]

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[48] See also SAFETY AND SHIPPING REVIEW 2019, page 7: "*Technological advances also means cyber losses will be an increasing feature of marine claims going forward. Companies are responding with an uptick in cyber security assessments while some insurers are looking to clarify so-called "silent" exposures. More contingency planning and stress testing of systems needs to be done to combat a growing number of loss scenarios*"

[49] SAFETY AND SHIPPING REVIEW 2019, page 31: *"It is estimated that 75% to 96% of marine accidents can involve human error. Furthermore, AGCS analysis of almost 15,000 marine liability insurance claims between 2011 and 2016 shows human error to be a primary factor in 75% of the value of all claims analyzed – equivalent to over $1.6bn of losses. Given the role of human error in so many incidents, the quality of crew and ship owners' overall safety culture are of increasing importance to risk assessment."*

[50] SAFETY AND SHIPPING REVIEW 2019, page 7: "*The growing use of connected technology in the maritime sector is a positive for safety and claims. Electronic navigation tools, ship-to-shore communications and the greater use of sensors have the potential to improve navigation and help avoid incidents. Sensors can also reduce machinery claims through performance monitoring and early intervention and help mitigate cargo losses. Yet, at the same time, accidents continue to happen due to overreliance on technology – even down to crew members being on their phones when a loss event occurs. A generation of seafarers has grown up trusting what they see on a screen but it is crucial that crew continue to have appropriate training and develop a solid understanding of the fundamentals of sound navigation and situational awareness."*

[51] SAFETY AND SHIPPING REVIEW 2019, page 41: "*With widespread use of autonomous ships unlikely to happen on the high seas anytime soon, early examples are likely to be limited to smaller vessels and coastal waters. Autonomous ships are predicted to reduce human error, a major driver of accidents, but crews are likely to have an important role on board vessels for the foreseeable future."*

[52] SAFETY AND SHIPPING REVIEW 2019, page 7: "*While there will be incidences where technology and automation will remove crew from hazard, innovation should not be driven primarily by efficiency and accounting. As ongoing issues with large container ships and fires and misdeclared cargo show – innovation and technology is not a panacea if the root cause of incidents and losses is not addressed"*

[53] *See "Autonomous ships in unchartered waters": "In Norway, it is already possible to conduct autonomous trials in test areas established by the Norwegian maritime authorities. There is close cooperation between the companies in the Norwegian maritime cluster and the authorities, which have expressed a wish to contribute so that Norway leads the way internationally on unmanned vessels. However, for international autonomous trade, transnational regulation is required – and the European Union and the International Maritime Organisation will play a deceive role."*

The cluster also has parts in Finland. For example, Kongsberg has offices in Turku and Rauma and there is also a testing area for the vessels in Satakunta. It can therefore be expected that as the Nordic conditions already seem to suit the purpose, the insurance conditions will soon be adjusted for the purpose of remote controlled and autonomous vessels. The key element to flexibility by the insurers could be the use of special safety regulation for the remote controlled or autonomous vessels. The risks are already being assessed for insurances for the vessels in local traffic in Norway and Finland and the solutions are expected in the near future as the vessels need to have their insurance cover when they are in traffic soon. The assessment of risk is easier with the ferries that have been on the same route before but are gradually transformed first to remote controlled and later autonomous ferries. The same gradual development will be expected with the first cargo vessels in Norway. Evaluation of the risks in these different stages of autonomy gives a good starting point for the hull insurers.

Nordic NMIP conditions seem to be the best basis for covering the risks, but competition for the market shares will probably force the other markets also to develop their legislation and conditions to more favourable terms for the assured by the time the remote controlled and autonomous vessels will be in international traffic. If the London market wants to compete, it needs to change its Hull clauses in the future. The changes in IMO conventions will take some time and those changes will have more effect on liability insurance than Hull insurance cover.

REFERENCES

[1] Autonomous ships in unchartered waters.in Maritime Cyprus admin. *https://maritimecyprus.com/2019/04/19/autonomous-ships-in-unchartered-waters/*

[2] CMI Webpages: *"CMI Spreadsheet on Conventions"* https://comitemaritime.org/wp-content/uploads/2018/05/Spreadsheet-Regarding-Conventions.xlsx.

[3] CMI Webpages: *"CMI International Working Group position paper on unmanned ships and the international regulatory framework"* https://comitemaritime.org/wp-content/uploads/2018/05/CMI-Position-Paper-on-Unmanned-Ships.pdf

[4] *CEFOR; The Nordic Marine Insurance Plan of 2013, Version 2019. Based on the Norwegian Marine Insurance Plan of 1996, Version 2010. http://nordicplan.org/The-Plan/*

[5] R. R. Cornah, R. C. G. Sarll and J. B. Shead, LOWNDES AND RUDOLF, The Law of General Average and The York - Antwerp Rules, 15th Edition, Thomson Reuters, 2018

[6] Falkanger – Bull – Brautaset, SCANDINAVIAN MARITIME LAW, The Norwegian perspective, 4th edition, Oslo 2017

[7] Marc A. Huybrechts, Marine Insurance law: A San Andreas Fault between the common law and civil law. pages 335-362 in The Modern law of marine insurance, edited by Rhidian Thomas. Volume 2, London 2002.

[8] IMO Webpages: "*IMO takes first steps to address autonomous ships"* http://www.imo.org/en/mediacentre/pressbriefings/pages/08-msc-99-mass-scoping.aspx

[9] John Reeder, BRICE ON MARITIME LAW OF SALVAGE, 5th Edition, 2011.

[10] N. Roos, "Autonomous Vessels - A Ship Master´s Status Now and In The Future," in *Book of Proceedings - 8th International Maritime Science Conference April,11th-12th 2019*, Budva, Montenegro, 2019.

[11] *SAFETY AND SHIPPING REVIEW 2019 An annual review of trends and developments in shipping losses and safety. https://www.agcs.allianz.com/content/dam/onemarketing/agcs/agcs/reports/AGCS-Safety-Shipping-Review-2019.pdf*

[12] Baris Soyer, Marine warranties: Old rules for the new millennium, pages 161-197 in The Modern law of marine insurance, edited by Rhidian Thomas. Volume 2, London 2002.

[13] Templeman – Gilman – Blanchard – Hopkins – Hart, Arnould: Law of Marine Insurance and Average, 19th edition, London 2018.

[14] Wilhelmsen – Bull, Handbook in Hull Insurance, 1 edition, Gyldendal 2007.

SETTING UP INPUT DATA OF MODEL FOR ASSESSING LEVEL OF A COUNTRY'S ACCEPTANCE OF PARTICIPATION IN THE INTERNATIONAL COMPENSATION REGIMES FOR OIL POLLUTION

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Summary

In this paper, three input parameters are proposed for modelling the acceptance level of a country's participation in the international compensation regime for oil pollution damage from ships. Arguments for selection and recommendations are analysed and presented based on current research. We analyse the data to model the assessment and the relationship between the factors affecting the levels as well as the level of acceptance of participation in a country's compensation regimes.

Keywords: oil pollution, international compensation regime, level of acceptance

1. INTRODUCTION

Considering the international regimes for compensation of oil pollution damage from ships and statistic data of the country members of the convention CLC 1992, Fund 1992, Additional fund 2003 we can see that two independent compensation regimes are existing. One of these policies with three levels is applied for oil tankers and the other with only one level is applied for merchant vessels that are not oil tankers.

These regimes state strict liabilities for the owners who have vessels causing environmental pollutions. These liabilities are limited according to vessels dead weight and require the owners to maintain an obligation of insurance or financial guarantee for their compensation liability. Beside that International Oil Pollution Compensation Fund (IOPC) supplies an amount of money to anyone who has not reasonably compensated for damage caused by oil pollution following CLC 1992. In case of the regime with only one level there is no additional fund compensated for environmental pollution from vessels fuel oil.

Vietnam is a coastal State with sea wider than the land area three times and more than 3260 kilometers of coastline with nearly 90,000 ships entering and leaving Vietnamese ports each year with a total capacity of over 320 million GT, of which 44,224 foreign ships [1]. Along with that, the annual amount of oil transported through the East Sea is about 2.1 billion tons and at any time there are about 51 large-sized tankers operating in the region [2]. Every year, if the number of oil leaks is about 1%, the amount of oil spilled into the East Sea is 2 million tons [3].

Most of the coastal countries has become members of IOPC [4]. This is a success of the international compensation regimes of oil pollution from ships worldwide [5]. Vietnam is a developing country with low average GDP [6] and environmental pollution is adequately considered. This matter is shown in the constitution 2013, and many relating laws. However, compensation regimes of oil pollution from ships has not been fulfilled and appear in different laws. Vietnam became member of many international conventions such as SOLAS 1974, CLC 1992, Bunker 2001…however has not become member of others such as FUND 1992, Additional Fund 2003 yet.

Based on the above study many researchers in Vietnam have proposed that Vietnam should join FUND 1992 and others such as OPRC 1990. Vietnam has not applied the spirit of CLC 1992 and Bunker 2001 for claming the environmental damages caused by oil pollution from ships. Almost oil spill cases have been solved via negotiation, conciliation or diplomatic methods in stead of bringing to court. That is why the compensating money is not high and reasonable enough [7].

This paper introduces a method of setting up the input data for a model used for assessing the acceptance level of a country's participation in the international compensation regime for oil pollution damage from ships. The purpose of the model is to assess the level of necessity for the nation to join FUND 1992 and consider the interest of joining it. We analysed data for building the model and the relation between effects that may affect the level as well as the acceptance level of a country's participation.

2. THE THEORETICAL BACKGROUND

2.1. The tiers of international regimes for compensation of oil pollution from ships

There are three tiers of international regimes for compensation of oil pollution from ships:

- *First tier,* CLC 1992 states that it is compulsory for ship owners of vessels from 2000T above to buy insurance of financial guarantee. Ship owner shall be responsible for any damage caused by oil spill into sea due to their fault. The victims shall ask for compensation from the ship owner’s insurer or financial guarantee.
- *Second tier,* in case the victim is not reasonably compensated corresponding to CLC 1992; the damage is beyond the ship owner’s liability corresponding to CLC 1992, the victim shall be compensated from IOPC Fund contributed by oil companies (FUND 1992).
- *Third tier,* Supplementary Fund 2003 provides an additional compensation for damages caused by pollution in countries that are members of FUND 1992. The criteria for compensation conditions in Supplementary Fund 2003 are similar to those of FUND 1992.

The above three tiers make it possible for ship owners and oil buyers to share financial burdens in compensation for the pollution damages.

Another compensation tier for oil pollution damage from ships other than oil tankers: Ship from 1000T above are compulsorily required to maintained an insurance or finalcial guarantee according to Bunker 2001 to compensate for victims affected by fuel oil pollution from ships.

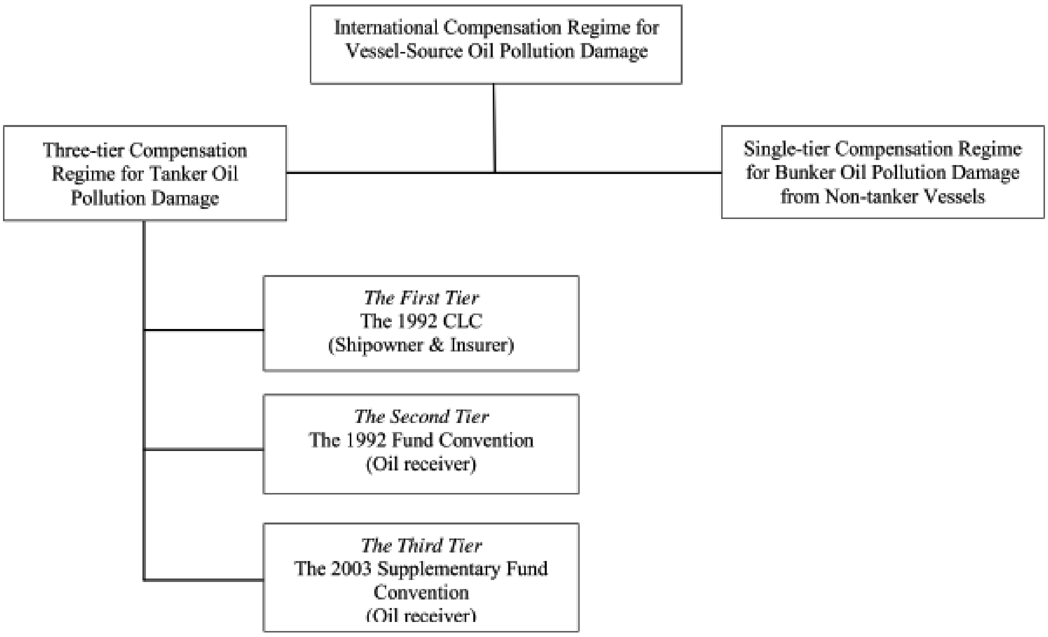

Figure 1 The international regimes for compensation of oil pollution from ships

Upto 2018 July 115 countries became members of both CLC 1992 and FUND 1992, 31 countries joined Suplementary Fund 2003, 23 countries joined CLC 1992 not FUND 1992, and 34 countries became members of CLC 1969.

2.2. The factors that affect the decision to join the international regimes for compensation of oil pollution damages from ships

Several studies in Vietnam have explained the factors needed for assessing tiers of acceptance of participation of the country in international compensation regimes for environmental damage due to oil pollution from ships. These factors have not been systematically mentioned so far in the world. Nevetherless a report of the United Nations Conference on Trade and Development (UNCTAD) presented some considerations for governers to assess the value of joining this convention [8]:

(i) level of risk of oil pollution from ships and potential damage to any national/local industry that might arise relating to huge oil spill;

(ii) relative interest of joining latest relating law means;

(iii) financial burden of joining relating international conventions;

(iv) current guarantting tier for whom affected by oil pollution from oil tankers according to national law or relating international documents approved by the country;

(v) assessing real value of regulations of relating international conventions.

3. DATA PROCESSING AND ANALYZING, CONSIDERATIONS SELECTING METHODOLOGY

Based on current facts of Vietnam we selected three considerations: two above mentioned considerations and one newly proposed consideration as following:

- Risk of exposure to tanker oil pollution,

- The relative benefits of adherence to the latest of the relevant international legal instruments and current levels of protection available to victims of tanker oil pollution under national law or under relevant international legal instruments to which a State is already Party,
- Level of Economic Development [9]

We study the factors that affect the decision to join the international compensation regimes for environmental damage due to oil pollution from ships. This is main results of this study.

3.1. Risk of exposure to tanker oil pollution

Vietnam is a coastal country located in very important position of politics and economy. Vietnam is close to one of the world's busiest and most important sea lane connecting Indian Ocaen and Pacific Ocean and vise vasa. That is the reason why we select this consideration.

Risk =Consequence * Probability [10].

Where *Consequence* is a function of many factors such as quantity and type of cargo being carried at the time of accident, efficiency of response to accident and the distance to economicaly and environmentally sensitive zone [10].

Probability consists of factors such as the density of traffics, sea and weather conditions, maritime risks, water depth, and sea bed natures [11]. Oil spills can not be predictable due to their particulars change by time and position and make it difficult to predict [11].

Since 1974, UN Environment seleted more than 143 countries to preserve and robustly manage common sea and coastal environment. Most of the countries has joined the Regional Seas Programme. There are 14 Regional Seas and 5 Partner Seas [12].

The reaserch team of ITOPF evaluated the risk perception in relation to the degree of preparedness in regional seas via providing overview of risk of oil pollution from ships [12]. The results are shown in the Table below.

Table 1 Levels of risk at Regional seas and Partner seas

Regional Sea/Partner Sea	Risk Category
North-east Pacific	Low 1
South-east Pacific	Low 1
Upper South-west Atlantic	Medium 2
Wider Caribbean	Medium 2
West & Central Africa	Medium 2
Eastern Africa	Medium 2
Red Sea & Gulf of Aden	Medium 2
Gulf Area	Medium 2
Mediterranean	High 3
Black Sea	High 3
Caspian	Medium 2
Baltic	Medium 2
North-east Atlantic	High 3
South Asian Seas	Medium 2
East Asian Seas	High 3
South Pacific	Low 1
North-west Pacific	High 3
Arctic	Low 1
Antarctic	Low 1

3.2. The relative benefits of adherence to the latest of the relevant international legal instruments and current levels of protection available to victims of tanker oil pollution

Major benefits of the country that joins the international regimes for compensation of oil pollution damages from tanker ships is "better placed to deal with the financial consequences of a tanker oil spill" [5]. It means that the victims of oil spill incidents will receive compensation from ship owners and oil buyers. According to regulations of CLC 1992, FUND 1992, Suplementary Fund 2003, there is no difference between victims, person who claims for compensation in all member countries should be equally behaved. However the maximum compensation money is different in each convention.

Joining international conventions relating to sea environment is one of the methods to overcome the sort of regulations for protecting environment and one of the main solutions to overcome sea environment poluution in Vietnam recently. It is also an important duty of international cooperation of Vietnam nowadays. These solutions make it easy for Vietnamese flag vessels operating in international routes and reduce insurance fee or easier for ship owners to get financial guarantee from foreign countries. Besides that, being crude oil exporting country ranking 33 in the world Vietnam can prevent the financial burden in joining FUND 1992.

Based on the approvement of international conventions up to 2018 July, the countries are categoried as followings:

- Not approved or joined any international conventions yet;
- Joined CLC 1969 only;
- Joined only CLC 1992 but Fund 1992;
- Joined CLC 1992 and Fund 1992;
- Joined CLC 1992 and Fund 1992 and, further more, Supplementary Fund 2003.

3.3. Level of Economic Development

In this study we proposed a factor of consideration the level of acceptance of participation in international compensation regime for oil pollution damage from ships named "Level of Economic Development" [9] because of the following reasons:

(1) Vietnam is a developing country with low medium GDP [15]. As other countries in the world Vietnam are facing the conflicts between development and environment protection. However Vietnamese government is aiming to robust economic development with equality between economic development and environment protection. To join relating international conventions, considerable sign is the country's economic fact [9].

(2) Most of the countries joining the international compensation regime for oil pollution damage from ships aim to compensating victims for oil pollution damage from ships fully and promptly, with the compensation money according to international regimes normally higher than that regulated in national laws. Furthermore, the countries joining international conventions to meet the world economic integration requirements also receive the technical and financial assistance from international organizations [17].

(3) The richer countries have more environmental protection activities than the poorer [18], and the people in countries with higher GDP tends to require higher environmental standards [19]. This agrees with the concept "Kuznets chart of environment" stating that the richer a society becomes the higher its attention to environment gets. That is why environmental standards requirements become higher [18].

To categorize level of economic development of the countries in the world, we based on World Development Index of year 2017 issued by World Bank. The countries' development are categorized according to their GNI (of year 2015).

- Countries with GNI lower than $ 1025 are considered low GNI countries;
- Countries with GNI from $ 1,026 to $ 4,073 are considered low medium GNI countries;
- Countries with GNI from $ 4,036 from $ 12,475 are considered high medium GNI countries, and
- Countries with GNI from $ 12,276 and higher are considered high GNI ones.

Using the above three selections, we proposed two supposition: (1) "Risk of exposure to tanker oil pollution" and "Level of Economic Development" are directly proportional to the tier of acceptance of participation in international compensation regime for oil pollution damage from ships, while that tier of acceptance is inversely proportional to Level of Economic Development and Financial burden when joining international conventions; (2) "Risk of exposure to tanker oil pollution" and "Current levels of protection available to victims of tanker oil pollution" are directly proportional to each other, anyway can be inversely proportional to "Level of Economic Development".

4. CONCLUSIONS

In this paper, three input fators are proposed in order to assessing the acceptance level of a country's participation in the international compensation regime for oil pollution damage from ships. The theoretical considerations for selecting and proposing are presented based on current studies. To evaluate the effect of the factors, in the next studies we will apply the method of fuzzy set theory to build a fuzzy model and simulate the results. Based on those results we will get necessary lessons for Vietnam in considering to join the international compensation regime for oil pollution damage from ships.

REFERENCES

[1] http://www.baogiaothong.vn/kha-phuc-su-co-tran-dau-tai-chinh-bo-ty-chu-tau-d14115.html. (accessed 15/12/2016)
[2] Hong Thao Nguyen, Sea environment pollution in Vietnam – Law and practices, Statistics Publishing House, 2003.
[3] Pham Van Tan, Dalian Maritime University, A Comparative Study of the Civil Liability Regime of International, China, Korea and Vietnam for Oil Pollution Damage Caused by Ships,2017
[4] Explanatory Note of IOPC FUNDS, 2018.
[5] The IOPC Funds' 25 years of compensating victims of oil pollution incidents, available at: https://www.peacepalacelibrary.nl/ebooks/files/332492354.pdf (accessed 05/05/2018)
[6] Decision 432/QĐ-TTg *12/4/2012* Approvement of Robust Development Strategy of Vietnam in period of 2011 – 2020.
[7] Nguyen P. H., Vu Q. S., "Practical implemention of law compensation for environmental damage caused by oil from ships in Vietnam", The Journal of Transport, No. 11/2017.
[8] UNCTAD Report of Liability and Compensation for Ship-Source Oil Pollution: An Overview of the International Legal Framework for Oil Pollution Damage from Tankers, Studies in Transport Law and Policy, 2012 No.1, at p 19.
[9] Bingying Dong, Ling Zhu, Kevin X.Li, "Acceptance of the international compensation regime for tanker oil pollution-And its implications for China", 2015)
[10] Colleen O'Hagan, "Use of GIS for Assessing the changing risk of oil spill from tankers", paper presented at 3rd Annual Artic shipping conference, st Petersburg, Russia, 17-20 April 2007.
[11] Irina Enache, Sabina Zagan, "Risk Assessment of oil marine pollution", in Exposure and risk assessment of chemical pollution-comtemporary methodology, 2009.
[12] T.H. Moller, F.C. Molly and H.M. Thomas, "Oil Spill risks and the state of preparedness in regional seas", 2003.
[13] Fifth Report of the Third Intercessional Working Group, Document 92FUND/WGR.3/15, para.10.1.
[14] CIA, The World Fact Book, Country Comparison: Oil Exports, Available at: https://www.cia.gov/library/publications/resources/the-world-factbook/rankorder/2242rank.html. (Accessed 10/10/2018))
[15] World Development Indicators, 2017 Publish by World Bank.
[16] Law University of Hanoi, General Theory of State and Law, People Police Publishing House, 2012.
[17] Law University of Hanoi, Environmental Law, People Police Publishing House, 2015.
[18] M. Sagoff, The Economy of the Earth, Cambridge University Press, New York, 2008.
[19] A. Franzen, R. Meyer, Environmental attitudes in cross-national perspective: a multilevel analysis of the ISSP 1993 and 2000, Eur. Sociol. Rev. 26 (2010) 219–234.

IMPACTS OF TRANSPORT ON THE EFFICIENCY OF THE SHIPBUILDING SUPPLY CHAIN

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Summary

The shipbuilding industry has changed dramatically throughout the world over the last decade, following the global financial crisis in 2007-2008. The continuing growth of the economy and the related seaborne transport has displayed positive trends in line with attractive oil prices. All this has positively affected the shipbuilding industry whose capacities have reached almost full employment. There is an exceptionally strong shipbuilding sector in the European Union, which could be further reinforced by forming a comprehensive shipbuilding supply chain. The intensity and dynamics of changes determined by globalization processes impose on modern business systems the continuous need for innovation and improvement. These days, the production systems, with their input-output transformation, are exposed to many visible and invisible effects that have significant impacts on the effectiveness and productivity of the ongoing processes. One of the most important determinant of the production process is the transport. It plays a key role in the economic performance as it enables safe and efficient distribution of goods and services along the supply chain. In addition, the transport connects various separate activities, thus significantly influencing the efficiency and profitability of their factors. One of the essential elements defining the functionality of transport is the choice of transport direction. Such a decision is determined by a number of factors that primarily relate to the criteria, evaluated or analysed when making such decisions, and to decision makers who, depending on the requirements and the needs of the service users, take into account different priorities and preference structure (severity) criteria. By choosing the optimum transport route, the service users can significantly influence the cost efficiency of their business, thereby the overall competitiveness as well. The dynamics and complexity of the market require making rapid and accurate decisions and minimizing the error occurrence. Therefore, this paper aims to emphasize the importance of a comprehensive insight into all external and internal processes affecting the production system, with particular reference to certain segments of the shipbuilding process. Creating a model for interrelated influences, between the external and internal logistic and transport activities on the individual segments of the production process, allows the corporate management to make the most appropriate and effective decisions. As a result, this work contributes to a wider understanding of the potential of predicting possible future events, including the impact of choosing optimal transport direction on the efficiency of the internal production process, in the event that there are several selection alternatives.

Keywords: shipbuilding supply chain, production system, competitiveness, transport direction, efficiency

1. INTRODUCTION

Production is essential for any society. It is the eternal prerequisite for the survival of the society and humans as individuals. Production is the process of human action on the resources, with the aid of transforming tools, aimed at creating goods or services that satisfy the needs of the society and individuals. Therefore, production depends on the consumer's need, i.e. demand (Figure 1).

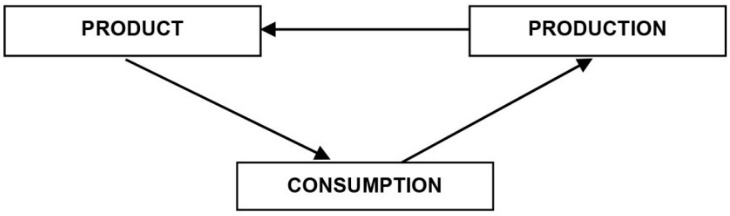


Figure 1 Interaction within a reproduction chain

Source: Rovan et al., 1996

Consumption and production are interrelated in the way that consumption stimulates production and the production enables consumption. Production has a priority as it is supposed to deliver maximum amount of quality products, including their variants for varied markets, at minimum production costs and minimum assets, within a short delivery time [10]. Production activities are performed within business systems that are incorporated into the economy and society through cooperation, transport, energy and market [12]. Business sub-systems, oriented towards the environment and indirectly associated with production, include system policies, production program, production policy, material and financial assets, human resources and organisation. The production system (Figure 2) is a business sub-system designed to meet the objectives of production, i.e. to obtain a product.

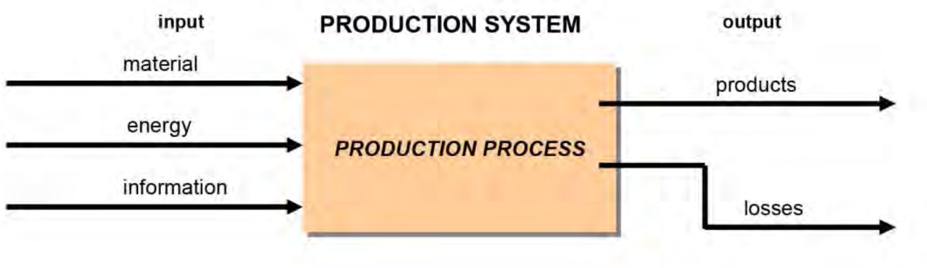


Figure 2 Diagram of events in a production system

Source: Rovan et al., 1996

The production process consists of the elements defining the product conception and the elements defining the end-product that is ready to be launched onto the market (Figure 3). The chain of events is called the production process. A production system may have one or more production processes that comprise the activities associated with the definition of the product, organisation of production, preparing the production materials, obtaining and storing the raw products, stages of component shaping and manufacturing, assembling the components, technical control, protection from external conditions, packaging, and all other activities that are related to completing the end-product [13].

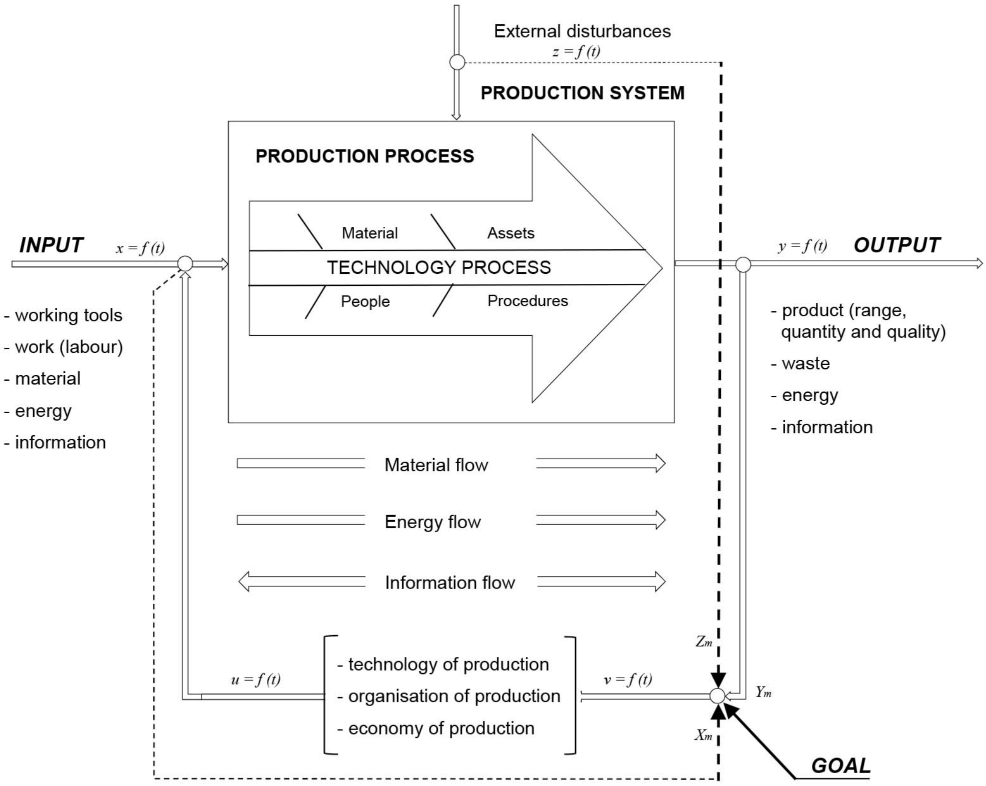


Figure 3 Elements of the production system

Source: Rovan et al., 1996

The basis of any production process is the production technology, whose application transforms the input values to achieve, as the output result, the goods or services that are transferred to the next stages of reproduction, next stages of processing, or consumption. The production system output is at permanent interrelation with the input through the feedback links and function sub-systems (at technology, organisation and economy levels), with the purpose of removing or reducing the disturbance values (internal and external disturbances), so that the production process could flow uninterruptedly, in line with the predetermined function of the production system. A production process represents an organisational solution to the technology processes that are taking place [12].

2. SUPPLY CHAIN IN THE SHIPBUILDING INDUSTRY

The supply chain may be defined at various degrees of scope, and various approaches are used to define the way it is managed. Some experts observe it through operational activities in the flow of materials, others describe it as a management philosophy or through the prism of management processes [7]. Despite various interpretations, there is a common and comprehensive description of the supply chain's role, whose importance may be defined as follows: a supply chain is a system whose components – material suppliers, production facilities, distribution services and users – are integrated through the flow of material and the feedback information [5]. The goal of the supply chain management is to synchronise the demands of the users for the flow of materials that are provided by the suppliers, in order to reach balance among the high output of the users, the low level of supply, and low unit costs [4]. It can be concluded that a supply chain involves all stakeholders, from the starting supplier to the end user, who are integrated with the flow of material, reverse flow of material, information flows (management and control) and financial flows. The supply chain management refers to the integration, coordination and synchronisation of the activities and processes performed by all participants in this chain of events – from strategic and tactical to operational activities. It must constantly be taken into account that each link in the chain affects the total cost and value of the product / service for the end-user. Transport is an essential support across all supply sectors. Transport services are relevant for the economic growth of all businesses so that national legislations provide various subsidies for the development of the traffic infrastructure [17].

2.1. Supply chain performance

Logistic performances can be seen as a sub-category of a wider notion of a company's or organisation's performances [21]. From this standpoint, they are multi-dimensional and can be classified as:

- Soft performances typically present a user's perception about the completed product or service, and are associated with efficacy and efficiency;
- Hard performances can be evaluated easily, accurately and at low cost; they can then be compared with the performances of other companies because these performances are typically associated with financial statistics and elements of cost statistics.

When logistic chains are observed through the theory of systems, logistic performances can be classified as:

- Internal (represent "internal" characteristics of the logistic sub-systems and refer to technical, technological, organisational, economic and other relevant features of these systems);
- External (represent the "result" of the functioning of the logistic system and reflect the level of quality and economy of the realisation of logistic processes, i.e. they reflect the logistic system and the way it function within the environment).

Given the fact that the supply chain is a broader system, compared to logistics, it is necessary to discuss and define the performances and measurements that match the specific nature of the chain. There are a number of issues related to this area:

1) Problem of the identification, definition and measurement of performances at the level of supply chain;
2) Problem of selecting measures for evaluating the performances of the supply chain;
3) Problem of the identification and definition of the performance measures, as well as the implementation of the measures in line with the needs of individual companies;
4) Problem that arises when, due to complexity of the processes taking place in the supply chain, it is not possible to apply just one performance measure in practice;
5) Problem of the retrospective treatment of the performance measures.

It can be concluded that the lack of adequate measures of performance, or their incorrect or different quantification in the supply chain, may result in errors in meeting the requirements and/or expectations of the user, local optimisation of performances of one stakeholder in the chain or one unit within a company, lost potential for increasing the competitiveness of the chain, and supply chain conflicts. Although each supply chain is unique, some of the performances and their measures can be applied in most situations and be grouped in four categories:

1) Performance – delivery. This is one of the most important performances in the supply chain. The value of this performance can be observed through its impact on the sales to users, which at the same time affects the competitiveness of the supply chain, and through its management potentials, which affects the quality of the supply chain. Literature and other sources define various measures for this performance, including service to the user, degree of fulfilling user's orders, just-in-time delivery, forecast accuracy, cycle of orders, etc.

2) Performance – flexibility. Defining the cycles of various processes across the supply chain represents a prerequisite for the definition and quantification of the delivery performance, i.e. some of its measures. Setting the length of these cycles can define the ability of a chain to adjust to market changes, which is one of the essential prerequisites for the survival of companies and entire supply chains in modern business environment. For this reason, a new performance has been designed, encompassing all cycles in the supply chain and describing the chain's flexibility. Generally speaking from the standpoint of performances, the flexibility is a system's feature that enables the stability of performances under conditions of changes, i.e. uncertainty.
3) Performance – capital and stocks. A number of experts believe that the capital management is the key to successful management of the supply chain. The supply chain capital typically comprises receivables, stocks, facilities and equipment owned by the supply chain. The most important performance measures of the capital management include:

- Working capital, defined as the relation between the revenues and the total capital;
- Money flow, a derived measure, representing the average time needed to get the return on investment, from the time of investment in raw resources until the time when the user pays for the product / service.

As for stocks, common performance measures include, from the physical standpoint:

- Stock turnover, defined as the ration between the overall consumption of material and the average stock balance over a period of time;
- Stock age, defined as the average time that the products spend in stock;
- Average stock level, representing a good performance measure for making comparisons of functioning of the supply chain in various scenarios.

4) Performance – costs. These costs make a very important performance as the goal of any company and supply chain is to make profit and increase their competitive advantage. One of the fundamental ways for achieving this goal is to reduce overall costs within the supply chain. The overall costs of a supply chain are typically a sum of the costs per processes performed in the supply chain. These processes vary with the specific structure of an individual supply chain, but generally include: cost of purchase, cost of production, cost associated with stocks, cost of transport and distribution, cost of storage, cost of using information technologies.

In addition, there are performances and performance measures that cannot be directly categorised into the above types. One of the frequent performances is associated with the supplier, which is applied when selecting the supplier. The choice of supplier can be also observed within the context of the supply chain efficiency, its integration, response, service level and reliability [15]. Naturally, prior to selection, it is necessary to carry out periodical analyses of the suppliers' performances, both short-term and long-term, from the viewpoint of development, strategic planning, and the like, in order to timely detect the abilities of a supplier to meet the requirements of users in the near and distant future. Along with the analysis of a supplier's performance, one has to take into consideration the relationships among the supply chain stakeholders and the effects of these relationships on the operation of the very chain of supply [22]. Most frequent considerations include the forms of partnership relations due to their impacts on the efficiency and efficacy of supply. Problems in defining a supply chain makes its modelling difficult and indirectly affects the choice of performances and performance measures within the supply chain.

2.2. Specific nature of the shipbuilding supply chains

The specific nature of the shipbuilding supply chain is determined by the complexity of the vessels as the end-products of various types and sizes, having high individual capital values. A vessel, as complex product, necessitates an equally complex construction process that requires, among other factors, a unique and specific organisation structure of the shipyard. The uniqueness and peculiarity of the organisation structure lies in its "scope", i.e. a large number of its business-production functions, and in its "depth", i.e. a large number of its organisational and management levels [6]. Furthermore, boatyards and shipyards have developed relationships with many partners that participate in the construction of vessels, both in preliminary and in production stages of the shipbuilding process (Figure 4). The processes of purchase, designing and, to a lesser extent, preliminary and other shipbuilding processes generate demands for the purchase of a wide range of construction material and consumables, equipment and devices, that are necessary for making a vessel or performing associated activities. The processes in the stage of purchase and storage of materials include the sub-processes of designing and sending inquiries to potential deliverers, commercial analyses of the offers, selecting the best supplier, making a contract of supply, enduring compulsory documents, arranging the financial documents, input control, receiving and storing material, forwarding from the warehouse, etc. [9]. The inputs in this process include the ordered specifications of material, equipment and devices, with all needed technical data regarding the material properties, prices and times of delivery. The inputs also include the information on the state of the market of materials, equipment and devices, and on the necessary funds for paying the materials, equipment and devices. The outputs in this process include the resources that are purchased, stored and ready for forwarding to other processes. The warehousing input control checks the suitability of the purchased materials, in terms of quantity and quality [8]. The resources needed for this process consist of local working resources but external resources can be engaged to do these tasks, e.g. companies specialised in the purchase of materials, equipment and devices. The purchasing and warehousing activities use IT technologies [19]. Although IT activities are extensively used in all stages of shipbuilding and are directly associated with the process of a vessel construction, the IT process is nevertheless considered as an auxiliary shipbuilding process.

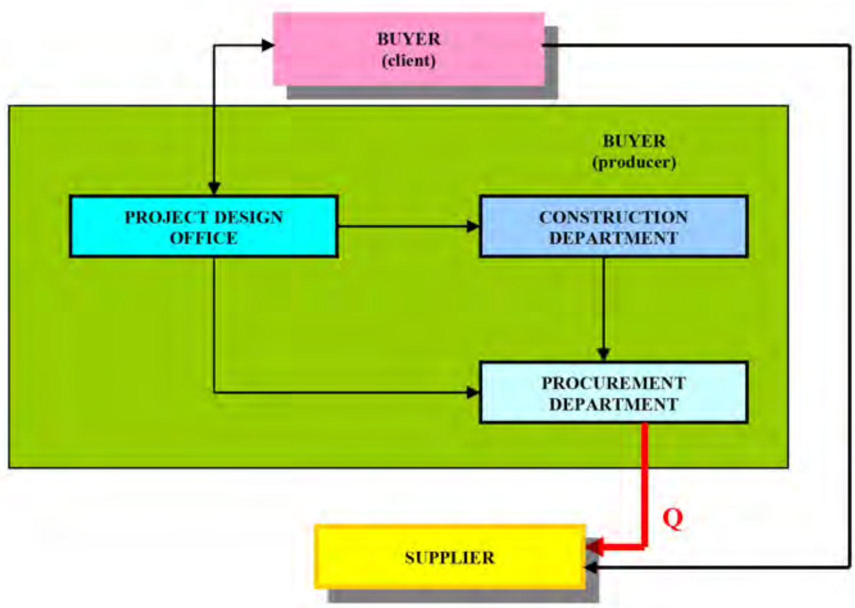


Figure 4 Relationship buyer-supplier in the shipbuilding production process

Source: Authors

Considering the value creation chain, shipbuilding producers are increasingly connected vertically in order to perform efficiently. They connect not only to control input costs but also to ensure access to strategic raw resources. Geographic proximity of the supply chain and the associated industries allow the metalworking and metal product industries to be flexible, reliable and on time. Some of the features of the modern shipbuilding are high level of specialisation, thereby adaptability to changes, production of cutting-edge products, efficient use of inputs, high level of recycling, intensive technological approach and strategic focus on innovation. Just like across the European Union, this industry is fragmented in Croatia due to a large number of small-size and medium-size enterprises, which allows them to rapidly adjust their production programs but, on the other hand, hampers the access to convenient finance sources and the cost reduction through volume economy.

3. TECHNOLOGY SYSTEM AS A DETERMINANT OF THE SUPPLY CHAIN

Technics, technology and production technology – the prerequisites of any production – play an important role in every-day life of humans, as their development directly affects the standard of living and the material environment of people [16].

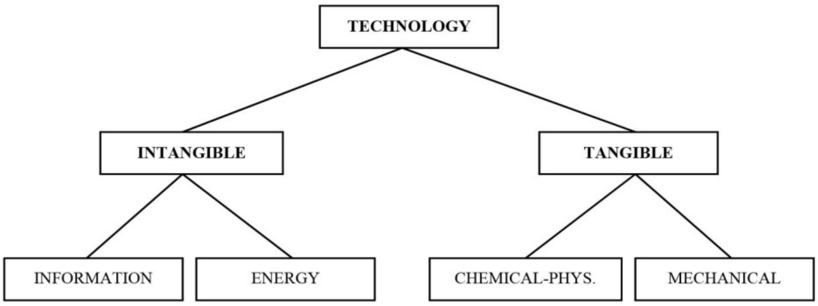


Figure 5 General classification of technologies in industrial production

Source: Rovan et al., 1996

Content, activities and level of development of technologies enable the technical independence and advancement of any economy and society. Technology encompasses all processes that generate products or services and is therefore closely connected with the economy and organisation [14]. It comprises of material and non-material processes and can thereby be divided into material (tangible) technology and non-material (intangible) technology (Figure 5). Material technology refers to the processing of materials and requires the participation and transformation of energy and relevant information. Non-material technology refers to transformation or processing of energy and information, as well as the processes associated with transportation, organisation of transport and storage, and testing of materials and products [12]. The technological system represents the basic component of the production system, designed to perform progressive changes from input conditions to output values. The technology system includes:

a) Processing system intended for performing the progressive change in material condition. Broadly speaking, the processing system is defined as the engineering system (machinery for processing the materials using adequate tools, equipment, installations and accessories) with the material processing as the basic function (main and auxiliary processes);
b) Manufacturing system intended for obtaining products of the designed shape and quality by assembling the components at manufacturing facilities, manual, semi-automatic or fully-automated assembly lines, with the aid of assembling machinery, and the like;
c) System of material handling is a part of the logistic system, as it ensures the transfer of the material intended for processing, auxiliary material, tools and devices between the processing lines and storage facilities. It consists of two inter-dependent sub-systems: material handling system and storage system. The transportation system is intended for performing transfer operations along the relation input – output, i.e. along dedicated flows (material flow, tool flow, equipment flow, waste material flow, etc.) by using adequate transfer-manipulation equipment (transport pullies, cranes, forklifts, conveyor belts, etc.) When the velocity of the transportation flow system drops to zero, it becomes the storage system. The latter is intended for adjusting to changes in the flow intensity due

to uneven duration of operations, system components failures or designed pause conditions – queuing, especially at the input and output of the system.

Creation of technologies is based on scientific concepts. It takes places in stages comprising ideas, selection of ideas, concept development, setting of variants, and comparison of the variants through conceptual and quantitative parameters [3]. Quantitative parameters of the technology include capacity, even flow of materials, delays, use of energy, and sensibility to disturbances.

Technological level of the production system depends on:

- Level of the technological development of a country (wealth, education, progress, investment policy)
- Level of the competition on the market (free import, giving preference to certain industries)
- Finance flows in the economy (investment policy, giving priorities or granting special status)
- Secondary effects of other industries (influence of IT technologies, development of forwarding and infrastructure).

3.1. Technological system of constructing marine watertight bulkheads at Brodotrogir

The function of the marine bulkheads is to divide a ship's hull into compartments. For various reasons, ship bulkheads are watertight, with the exception of wash bulkheads. Transverse and longitudinal watertight bulkheads are constructed in line with the requirements of the classification societies and their basic job is to prevent excessive flooding of the ship's interior. They prevent a vessel from sinking in case of the penetration of water into the hull, but they also prevent spreading of fire. In addition to the safety of the vessel and human lives, watertight bulkheads are designed to protect the marine environment from pollution by preventing the leakage of oils and other harmful substances from the damaged ship's tanks. In terms of ship structure, bulkheads increase the longitudinal and transversal strength of the vessel. In addition to watertight bulkheads, vessels are fitted with the bulkheads that divide the tanks and holds. They withstand additional loads and are carefully designed to indirectly improve the strength of the hull. They may be fitted with girders supporting the deck, bottom or sides of the vessel. They also support the deck superstructure and equipment. The grooves of the corrugated watertight bulkheads may be horizontal or vertical. In horizontal groove design, the thickness of the plates can be gradually increased towards the bottom, which makes the entire construction somewhat lighter, but such a construction is less efficient in withstanding compression stresses acting from the ship's bottom and the deck, and is often damaged in practice [6].

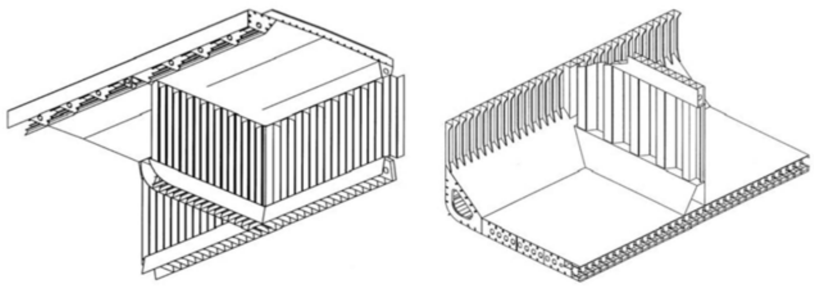


Figure 6 Transverse and longitudinal watertight bulkhead with the girder structure in a liquid bulk carrier

Source: Čagalj, 2009

Vertical grooves make bulkheads somewhat heavier than when the bulkheads are fitted with horizontal groves. However, bulkheads with vertical grooves are lighter than the structure fitted with pillars and stanchions, and withstand compressive stresses more efficiently. In tankers, longitudinal bulkheads typically have longitudinal horizontal grooves that contribute to the ship's longitudinal strength (Figure 6). Corrugated bulkheads have the advantage of being lighter, easier to design, easier to clean due to their smoothness, and they facilitate cargo handling. The downsides of the corrugated bulkheads arise from the technology of bending flat plates in a cold press and mould procedure, where the bends are more prone to corrosion than the remaining bulkhead surface. This problem is addressed by protective coating or by fitting angular bulkheads made of welded strips.

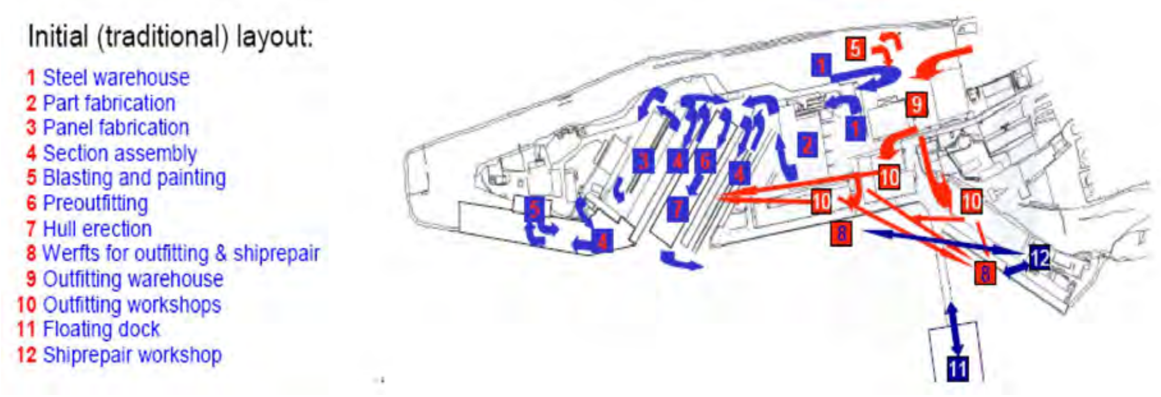


Figure 7 Brodotrogir shipyard layout and flow of materials

Source: Rovan et al., 2006

Technology of producing corrugated watertight ship bulkheads has several specific stages, i.e. processes:

- Receiving raw resources – plates (position 1 in Figure 7)
- Blasting and painting (position 5 in Figure 7)
- Tracing (marking the positions of reforming)
- Bending – shaping.

All the stages have specific principles that are directly related with the degree of the technological development of the organisation. This very fact ensures a specific nature of the production of ship's bulkheads at Brodotrogir shipyard. Inability to independently perform the last stage (bending – shaping) in the process of producing corrugated bulkheads imposes certain procedures at early stages (supply of raw resources) on Brodotrogir shipyard [11]. The lack of working resources (machinery for bending plates of larger thickness) determines the logistic-distribution chain to a large extent, making the external transport a significant cost determinant. In addition to the above-mentioned technological constraints, the internal flow of materials (Figure 7 and Figure 8) and the geographic site of the company (Figure 9) are in a direct interaction with the external transport activities and their organisation.

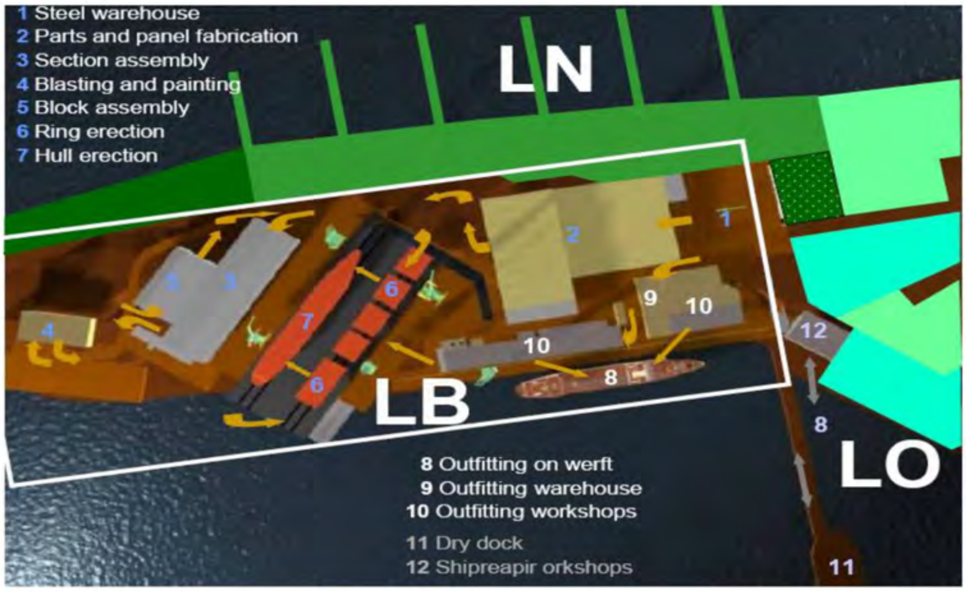


Figure 8 Layout of Brodotrogir as a compact shipyard

Source: Rovan et al., 2006

The quality of the logistic-distribution chain is defined precisely by the quality of connection between the internal and external transport, which is measurable by the rate of material flow through the overall production system [20].

Figure 9 Geographic location of Brodotrogir shipyard

Source: Rovan et al., 2006

Modern organisations tend to establish the so-called “pull systems”, whereby the end user “pulls” the needed resources (material, human, etc.). This concept reduces the possibility of unnecessary accumulation of material, human and other resources, which – from the standpoint of the costs – increases the competitiveness of the enterprise. On the other hand, there is a risk of shortage of needed resources at the moment of the end user's demand. This fact forces the executives to design a comprehensive approach to the logistic-distribution chain management.

3.2. Influence of the transport system on the supply chain function

When observing a transportation system as a whole, it can be noticed that the performance of the supply chains has a key role and must therefore be carefully considered. Optimal organisation in the transport engineering has to complete three basic tasks: achieving maximum cost-effectiveness, profitability and productivity [18].

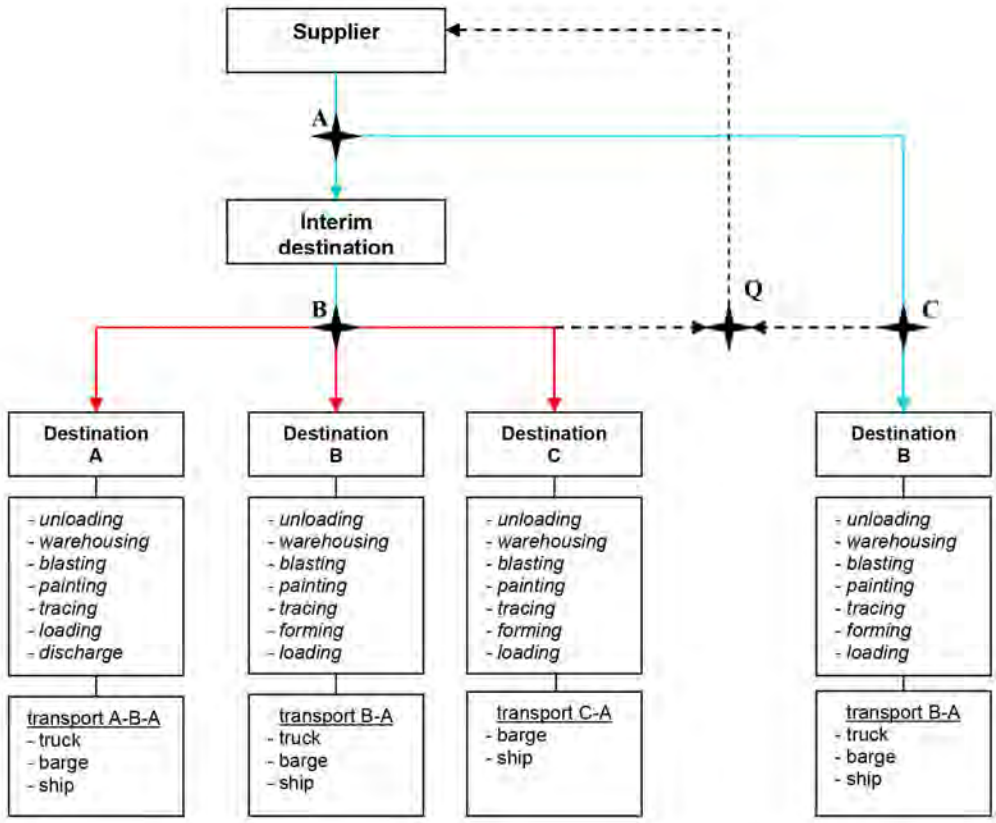
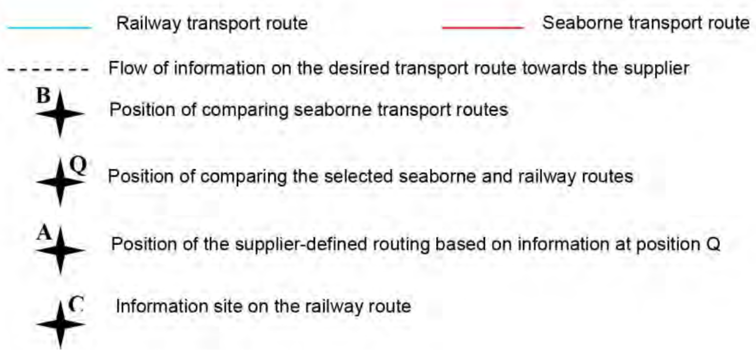


Figure 10 Method of planning transport routes in the function of the shipbuilding supply chain

Source: Authors

Where:



The method of planning transport processes in the function of supply chains represents a planning system where the supply chains are given the priority and are, accordingly, carefully organised and planned (Figure 10). Naturally, the organisation of supply chains cannot be planned separately, so this method also implies the planning of the logistic infrastructure, information system and control system, whose functioning is described by the performance indicators. The functioning of the overall system is largely affected by the end-users (buyers) whose responses are monitored carefully, so that certain elements of the system could be modified in line with their preferences [2]. In the market and dynamic economy, the industry and trade increasingly tend to reduce costs through flexible exploitation of resources, e.g. through permanent growth of outsourcing. For these reasons, and for the functions being implemented through the logistic infrastructure, the new strategies increasingly use these resources in a very flexible way in order to meet peak demands. All these changes affect the transformation of the profit of the logistic infrastructure in terms of expanding its function through the realisation of complementary activities and adjustments to the needs of the economy, which adds a new quality to the process. In terms of economy, the infrastructure of expenses is a very motivating factor, due to the high-rationalised potentials in cost reduction, improvement of the marketing position of all related economic entities, and the improvement of the economic structure of the entities in the environment. Their planning and exploitation are very demanding tasks due to their complex structure and ambivalent system of goals. The entities involved in achieving the goals are heterogeneous: logistic services providers, employees, industrial and trade enterprises, residents and local government. The primary goal of some entities has its sub-goals: improvement of the economic structure, unburdening of the traffic, improvement of economic conditions, etc. [1]. The goal of the supply chain organisation is to increase the competitiveness and profitability of an enterprise and the entire network, including the end-user. For this reason, the integration of processes and the initiative for re-engineering the supply chains should be achieved by increasing the efficacy and efficiency of all processes through all entities. The supply chain management, whose task is to achieve maximum competitiveness of the chain, consists of three major interdependent elements:

- Structure of the supply chain network (configuration of its members and their interconnection),
- Business processes in the supply chains (activities creating specific output which the user sees as value),
- Management components in the supply chains (allowing integration, structuring and managing the business processes).

3.3. Structure of the supply chain network

The supply chains involve all business entities, from the production companies and companies trading raw resources to the end-users. Management of such a network depends on various factors, such as: product complexity, amount of available suppliers and raw resources, type of services, available capacity and information, and the like. It is necessary to consider the length of the supply chains, the number of suppliers and users at each stage, as it rarely occurs that one company participates in only one supply chain. A number of research studies have revealed that there are three aspects of considering the supply chain structure: members of the supply chains, structural dimensions of the network, and various forms of business relationships across the supply chain [1].

After defining the network structure, it is necessary to define the members of the supply chain. If all entities are taken into consideration, the entire network may become very complex, as the number of members increases at each level. Integration and management of all relations among all members across the supply chain would most likely become counter-productive, if not impossible. For this reason, it is necessary to determine the essential members that contribute to the largest extent to the performance of the company and the entire supply chain. These members typically include the enterprises or organisations that the central company cooperate with, directly or indirectly, from the starting to the end point of the chain. However, when managing a complex network, it is necessary to distinguish the primary members from the secondary members, i.e. the ones that provide support. Primary members of a supply chain are all autonomous companies or strategic business entities that carry out operational and/or managerial activities in business processes, which are designed to create a specific output for a user or market. Primary members are supported by secondary members that provide resources, know-how, services or other goods. Secondary members typically include banks, real estate owners, companies supplying equipment for producers, marketing material or any kind of temporary assistance. They significantly contribute to the functioning of the supply chains although they do not participate directly nor they perform activities in value-adding processes during the customisation of the product for the end-user. The difference between the primary and supporting members is not always clear. For instance, a company can be a primary member and a supporting member of a supply chain. It may carry out primary activities for a process and supporting activities for other processes.

The definition of the primary members and the ones that provide support allows for defining the source point and the final point within a supply chain. The supply chain's source point occurs where the primary suppliers do not exist. At the source point, all suppliers are the ones that provide support. The consumption point, or the final point, occurs where the process of adding value does not exist any longer, i.e. that is the point where the product is consumed or the service ends [1].

As for the structural dimensions of the network, there are three basic dimensions of the supply chain networks: horizontal, vertical, and the horizontal position of the central enterprise. Horizontal structure refers to the number of stages in a supply chain. The latter may be long, featuring numerous stages, or short, with just a few stages. Vertical structure refers to the amount of suppliers and users at each stage. A company may have a narrow vertical structure, with several minor companies at every level, or a broad vertical structure having a number of suppliers and/or users at every level. The third structural dimension is the horizontal position of the company within a supply chain. A company may be positioned close to the initial source of supply or close to the end-user, or anywhere between these extreme points of the supply chain. In practice, there are various combinations of the above structural variables. For example, on the supply side, the network structure may be narrow and long, while on the user side, it can be wide and short. This implies that a change in the amount of suppliers and/or users, the supply chain structure can be affected at various stages and levels [1].

4. CONCLUSION

Changes in economy and ways of doing business (globalisation, intensive economy growth and development, protocols on environmental protection, etc.) have encouraged all participants in the logistic networks to pay more attention to transport system management, both in their internal and external business activities. In order to achieve cost-efficiency of these activities, the elements of integration have been incorporated in the supply chain networks, thus making the business processes (essential for transforming raw resources into products) to be most intensively exposed to changes within their business environment. This also applies to shipbuilding which, as a complex production system, has to gear its future operations toward achieving adequate standards of performance. In order to do, one of the first steps will be the rationalisation of the supply chain. The transport connects the processes of engineering and assembling into a more or less continuous flow. The transport of materials in the shipbuilding process cannot be therefore observed as a separate function but as a constituent part of the production process. Given its function in the shipbuilding process, transport directly and indirectly affects the level of production costs. In some segments of the production process, the share of transport costs amount up to 50%. To design the transport means to select the appropriate ways of transportation, and to design the transport among individual shipyard facilities means to define the means of transport and the ways of transportation across the shipyard's individual facilities and plants. Here, the structure of the supply chain is greatly determined by technology, particularly the exchange of information data, the fast response delivery system and the system of the efficient responding to demands. There are a number of ways for improving the performance of the company by improving the supply chain management. Several interdependent elements are essential for the efficient application of the supply chain management program. These include long-term relationships, information exchange and the strength of the supplier – financial, operational and technical – with regard to the products that are produced and delivered. The most relevant factors affecting the supply chain include the reduction in the number of suppliers, transport efficiency, increase in competition, shortening the life cycle of the products, and technology. Today, companies are considerably reducing the number of their suppliers as part of their supply chain programs. At the same time, these companies have managed to increase the range of products for their clients. Fierce competition also affects the supply chain. Globalisation is a ubiquitous trend to rationalise production and transport costs, which can be also seen as the synergy between industrial production and transportation. By introducing modern technological solutions to the transport chain, it is possible to achieve a higher quality of transportation, provide quality groundworks for the sustainable development, efficiently implement the environment preservation measures, and increase transport capacities at reduced costs. This study has revealed that the level of the technological development of a shipbuilding system considerably determines the creation and design of the transportation and logistic activities, thereby the overall shipbuilding supply chain. Therefore, the strategic development of any organisation requires comprehensive consideration of the role of transport in increasing the performance efficiency, which is the fundamental prerequisite for the sustainable and long-term market competitiveness.

REFERENCES

[1] Babić, D. (2006) *Metode planiranja logističko distribucijskih procesa.* Master's paper. Faculty of Transport and Traffic Sciences in Zagreb, Croatia

[2] Bojić, J. (2015) *Postupci i metode planiranja logističkih procesa*. Master's paper. Faculty of Transport and Traffic Sciences in Zagreb, Croatia

[3] Borna, B. (2006) *Projektiranje procesa i strukture organizacije*. Sinergija. Zagreb, Croatia

[4] Bloomberg, D.; LeMay, S.; Hanna, J. (2006) *Logistika*. Mate. Zagreb, Croatia

[5] Chopra, S.; Meindi, P. (2004) *Supply chain management*. Prentice Hall

[6] Čagalj, A. (2006) *Prilog modeliranju organizacijsko – tehnološke strukture suvremenog Brodogradilišta*. Doctoral dissertation. Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture in Split, Croatia

[7] Deljanin, A. (2007) *Logistika u transportu i komunikacijama*. Faculty of Transport and Communications in Sarajevo, Bosnia and Herzegovina

[8] Ferišak, V. (2000) *Elementi managementa nabave.* Self-published. Zagreb, Croatia

[9] Ferišak, V. (2006) *Nabava: politika-strategija-organizacija-managment*. Self-published. Zagreb, Croatia

[10] Porter, M. E. (2008) *Konkurentska prednost*. Masmedija. Zagreb, Croatia

[11] Rovan, M.; Geić, M. (2006) *Tehničko-tehnološka opravdanost restrukturiranja Sektora Brodogradilište*. Studija Brodotrogir d. d. Trogir, Croatia

[12] Rovan, M.; Veža, I. (1996) *Proizvodni sustavi*. Teaching material. Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture in Split, Croatia

[13] Schroeder, R. (1993) *Upravljanje proizvodnjom – odlučivanje u funkciji proizvodnje*. Mate. Zagreb, Croatia

[14] Sikavica, P.; Novak, M. (1999) *Poslovna organizacija*. Informator. Zagreb, Croatia

[15] Segetlija, Z. (2008) *Uvod u poslovnu logistiku*. Faculty of Economics in Osijek, Croatia

[16] Thakor, A. (2005) *Kako postati bolji stvaralac vrijednosti*. Mate. Zagreb, Croatia

[17] Varjan, P.; Konečný, V.; Gnap, J. (2018) *Research on Relationship between Freight Transport Performance and GDP in Slovakia and EU Countries.* Naše more - International Journal of Maritime Science & Technology. Vol. 65. No 1. pp 32-39

[18] Vukić, Đ.; Mašće, I.; Pavličević, E. (2017) *Upravljanje prijevozom kontejnerskog broda s ciljem optimizacije troškova*, Naše more - International Journal of Maritime Science & Technology. Vol. 64. No 3. pp. 76-80

[19] Žibret, B. (2007) *Strateška nabava*. Mate. Zagreb, Croatia

[20] Zelenika, R. (2005) *Logistički sustavi*. Faculty of Economics and Business in Rijeka, Croatia

[21] Zelenika, R.; Pupavac, D. (2008) *Menadžment logističkih sustava.* Faculty of Economics and Business in Rijeka, Croatia

[22] Zekić, Z. (2000) *Logistički menadžment*. Glosa d.o.o. Rijeka, Croatia

MODEL OF RATIONALIZATION OF TRANSPORT COSTS FOR THE CONSTRUCTION OF A SHIP HULL - Case study for the Brodotrogir

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Summary

The complexity of the worldwide market demanded from organizations to focus on all elements of their business. Insufficient quality in the insight of effects of different internal and external factors that have affected a company can be devastating for its survival. Models of the creation of added value became elements of excellence. These elements provided preconditions for market competition of the company at all important worldwide markets. Therefore, Croatian shipyards including the Brodotrogir company have to strive to maximum rationalization and optimization within their production process. The current approach to focusing exclusively on production while neglecting all other supported activities is considered as no longer sustainable. Also, it is concluded that such an approach does not provide achieving the desired level of competition. Therefore, the need for more intensive action in terms of improvement of the functioning of activities following production is inevitable. Transport is considered as one of these activities. Regarding that, this scientific discussion clearly elaborated the effect of transport on costs of the production process in shipbuilding, using a more detailed analysis within the segment of construction of a ship hull. The aim of this paper is to indicate large possibilities which transport activity can provide for the improvement of costs efficiency of the Brodotrogir company. Besides the simulation method, this discussion uses methods of induction and deduction, and descriptive method.

Keywords: Rationalization, Optimization, Transport, Construction of a ship hull

1. INTRODUCTION

The current exclusiveness related to analysing of added value within the production process of Brodotrogir Company neglected certain activities that were not directly connected in production. The contemporary approach to the organization of a company, based on competition elements determined the direction of actions toward rationalization and optimization of all segments of the production process. Important segments included transport activity, which connected other activities within the production process. Furthermore, transport included one-third of logistic costs and as such, it is considered as inevitable in the entire production procedure: from construction to shipment to end users and back [1]. Transport activity provided the movement of goods and products and ensured real-time and regional efficiency in order to create added value according to the principle of the smallest costs. Using well-prepared transport activity, it is possible to get the raw material (product and semi-product) to the right place at the right time in order to satisfy consumers'/users' demands. It is important to point out that actual shipping costs also involve the overall quantity of delivered cargo and its value that is calculated on the basis of the shipping costs per ton of cargo ton [8]. According to that, transport represented the precondition of efficiency and connection between consumers/users and producers. Depending on the type of production process, the rationalization of transport costs can be achieved within individual phases of the same process. Results on researches related to external, internal and manipulative costs of transport for the phase of construction of the ship hull created an economic paradigm for suggesting of models of rationalization of external, internal and manipulative costs of construction of the ship hull in the Brodotrogir Company. This paper indicated on the need for management of transport activities in order to achieve continuity of material resources through the production process. The simulation model can be a simple way for demonstrating the effect of external transport on cost efficiency of operating (internal) transport, and on the competitiveness of the Brodotrogir Company. Dynamic with which organizations are faced nowadays imposes making of quick and precise decisions, within which the factor of mistake needs to be minimized as much as possible. Therefore, simulation as a tool which provided the possibility for making the most optional and most correct solutions is considered as inevitable in the process of management of the modern organization.

2. IMPORTANT FEATURES IN PROCESS OF CONSTRUCTION OF THE SHIP HULL

According to their features, shipyards are considered as very complex business - production systems. This complexity is a result of the complexity of its final products – floating objects as individual products with high capital values and which are sorted by various types and sizes. Such a complex product also demanded a complex shipbuilding process which partially included unique and special organizational structure of the shipyard. The uniqueness and specificity of the organizational structure is reflected through its "wideness" or the large number of business -production functions and its "depth" or the large number of organizational – management levels. Regarding process in other industries, this might be considered as the atypical business – production process in which many problems related to shipbuilding process also appear. Such problems are related to efficiency, the time needed for the production process, manageability etc.

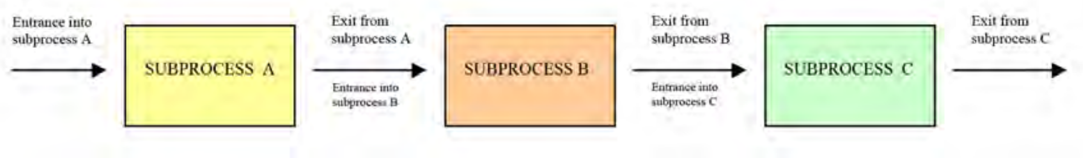

Figure 1 Chain of mutually connected processes

Source: Authors

Individual processes rarely appeared alone in the complex business – production processes. They presented a chain of mutually connected processes. Exits from the one process are usually considered as a part of entrance into following processes, as it is presented in the Figure 1. Analysis of the shipbuilding processes implied the conclusion that the group of processes is extended on the entire ship building process. The second group of process is related to the preparation part of the shipbuilding process and the third group is related to the production part of the shipbuilding process.

Processes related to the entire shipbuilding process are following:

- Development process,
- Management process,
- Financial – accounting process,
- Process of HR management,
- Process of general administration, and
- QA/QC process.

Processes related to preparation part of the shipbuilding process:

- sale process (Sale process in shipbuilding activity is significantly different than the sale process in other industries. The main difference includes the fact that the consumer/buyer appears at the beginning of the process rather than at its end.),
- designing process (Agreement on the floating object is followed by process of its designing. It is considered as continued development of the project of the floating object, started during the sale process.),
- construction process (Designing process if followed by process of the construction of the floating object. The main activity of this process is the development of performing/work documentation:
- process of development of the technology of designing (Aligned with sale process, designing process and construction process, process of development of the technology of designing of floating object is observed. This process includes significant interaction between mentioned processes.),
- process of procurement and warehousing of mounting material (Sales process, design process and part of shipbuilding process including preparation process generate demands for procurement of the wide spectrum of mounting and expendable material, equipment, devices needed for construction of floating object or providing of all shipbuilding processes.).

Processes related to the production part of the shipbuilding process:

- process of the relationship with partners in production (Due to uneven load of capacities, lack of own capacities, and occasionally needs for specific jobs, shipbuilding production processes include continuous need for additional working capacities from the environment. Therefore, there is a need for process of relationship with partners.),
- process of the steel processing (Process of the steel processing is the first of shipbuilding processes and it is divided on sub-processes of pre-processing, cutting, shaping and sorting of developed elements of the hull, using metal sheets and profiles.),
- process of completing of hull sections (This process can also be divided on sub-processes related to development of subassemblies and assemblies, flat edged panels, flat volume sections, flat plate sections, curved and very curved sections.),
- process of the assembly of the hull and handover of the floating object to water authorities (This process can be furthermore divided on sub-processes of assembly of the hull sections, welding of hull sections, finalization of the hull construction, assembly of scaffolding and process of handover of the floating object to water authorities.),
- process of equipping of floating object (This process includes large number of sub-processes such as: development of piping, electric, carpenter equipment, development of modules and blocks of the equipment, individual assembly of machines, devices etc.),
- process of anticorrosive protection (This process can be considered as final production process in construction of floating object.),
- process of the support to production processes (As it is already mentioned, important element for performing of productive shipbuilding activities includes conditions for conduction of production activities. These entrances represent exits from processes of support to productive shipbuilding processes.),

- process of maintaining of work resources (Considering large number of work resources and shipyard objects, process of their maintaining is important in the shipbuilding process. The process of maintaining is divided on sub-process of regular maintaining and sub-process of investment maintaining of work resources.).

Mentioned processes can be further divided on basic or key processes which directly participate in preparation or construction of the floating object and on auxiliary processes which are in function of support of basic processes. In other words, these processes participate in preparation or construction of the ship in indirect way. These days shipbuilding is focused on finding technical and technological solutions that would increase the cost-effectiveness of vessels, which is related to the profits they make [9].

3. ANALYSIS AND ESTIMATION OF EXTERNAL AND INTERNAL TRANSPORT COSTS OF CONSTRUCTION OF THE SHIP HULL

The main task of the transport in industry (external and internal transport or transport in production) is to ensure the continuous flow of materials and other elements within transformational process. The flow of the material includes all movements (transfers) of materials in order to perform operations in production process [5]. The transport process includes realization of all activities related to transferring of materials from the starting point to the destination.

There are significant differences between following transport systems:

- in area of traffic – external transport (by road, rail, sea, river and air),
- in area of production – internal transport.

Transport system in the company is important in many ways and it includes different features. Mechanization and automation of transport, except by kinds and performance of elements, also depends on level of integration of transport system and processes within production process. Mechanization includes application of machines rather than human force for achievement of materials flows. The fact important for this transport is that it is partially integrated with production process and occasionally in a whole. Automation of transport can be achieved through total integration of materials flows and information flows [2]. In case that transport system in the organization wants to achieve cost efficiency, it must have significant actions related to continuous improvement of following elements:

- Human resources – They represent the basis for development of the strategy of the company, while all other resources (machines, raw materials and capital) originate from people and they are derived according their action. Intensity of effect of human resources on efficiency of transport system should be observed in this direction. It is determined by continuous education work.
- Transport resources – They are considered as an important element in frame of success of transport system through different areas of effect. It is important to mention differences of their use within certain production system. Specificity of transport resources of shipbuilding production system is determined by technical – technology and functional features.
- Objects, transport roads and other infrastructure elements represent the third element which has the significant effect on the transport system of each production process, including shipbuilding process.

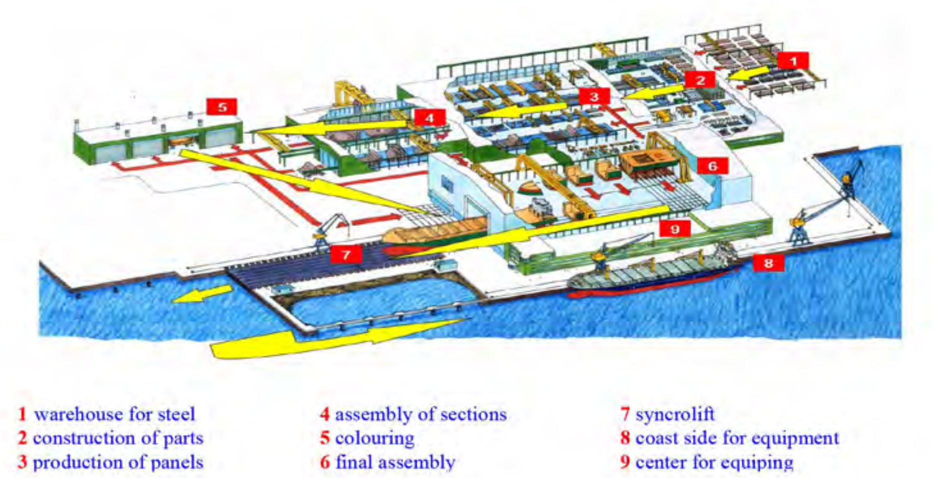

Figure 2 Modern prefabricated shipyard with following objects, transport roads and other infrastructure elements

Source: Rovan et al., 2006

Each of mentioned elements impacted on quality of transport system for providing certain activities in its own manner. One of important features of transport system for shipbuilding production process included the area where transport activities are conducted. Beside transport by road, certain transport activities are conducted by sea waterways where certain floating vehicles predicted for transport of certain load participate in such transport. Level of mutual action of mentioned elements determined quality of transport product.

Firstly, it can be observed through flow of elements through production process (Figure 2). Due to its complexity, efficiency of shipbuilding process is significantly determined by the quality of the transport product. Hence, there is a need for continuous improvements in that area of work. So far approach to monitoring and analysis of effects of transport costs on business of the Brodotrogir Company did not provide clear detection of deviation points. Costs of transport activities are mostly presented as separable element within the total cost which can provide the illusion of success. Regarding that, it is important to make analysis of transport costs (external, internal and manipulative) for one segment of the shipbuilding such as construction of the ship hull and to use the certain model for presentation of existence of significant space for rationalization of these costs. Costs of transport and manipulative activities within the structure of total costs appeared at the beginning of the production process (Figure 3), and they appeared in different forms continuously through timeline of construction of the ship hull and the entire ship. "Secrecy" of costs for transport and manipulative activities in the entire process, their lack of segmentation merely determined the efficiency of the organization itself [4]. Multiplication effect of these costs lead to minimized concreteness at worldwide shipbuilding market.

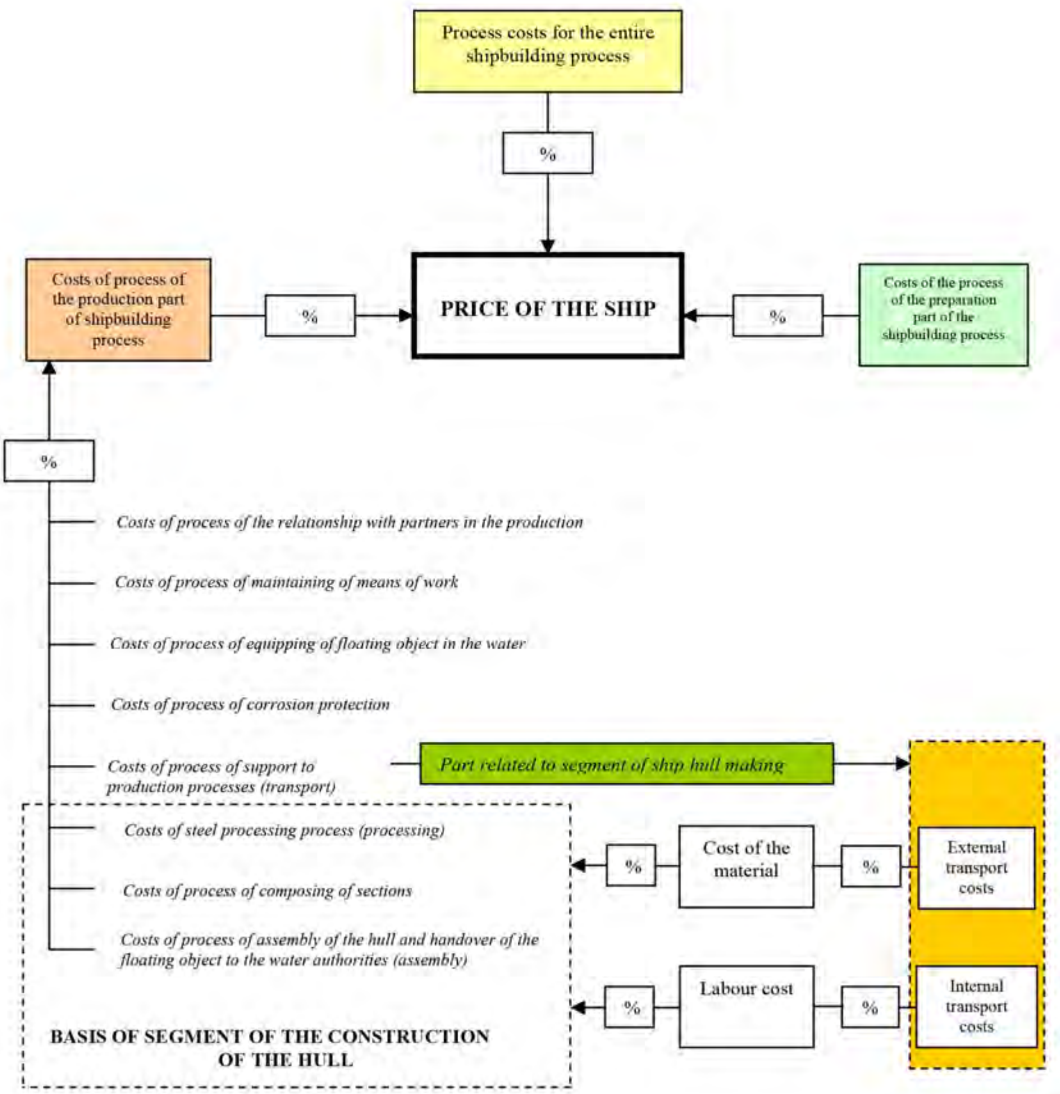

Figure 3 Structure of costs within the price of the ship

Source: Rovan et al., 2006

Therefore, the primary objective of this scientific discussion is to clearly define and numerously present the way how rationalization of external and internal transport costs impacts on competitiveness of the Brodotrogir Company.

3.1. The rate of external transport costs for construction of the ship hull

Overall globalization of material and informational flows have changed the perspective on meaning of logical activities including transport activities related to competitiveness of the organization. In that way, external transport is no longer observed only as a cost. It became an element which can be used for achieving of certain competitiveness relating the competition [11]. However, it is only possible to achieve if there is a clear explanation how the external transport activity increases added value to the product or the service. One of such ways included systematic following of transport costs from the location of shipment to the final takeover of the product or service to the potential buyer.

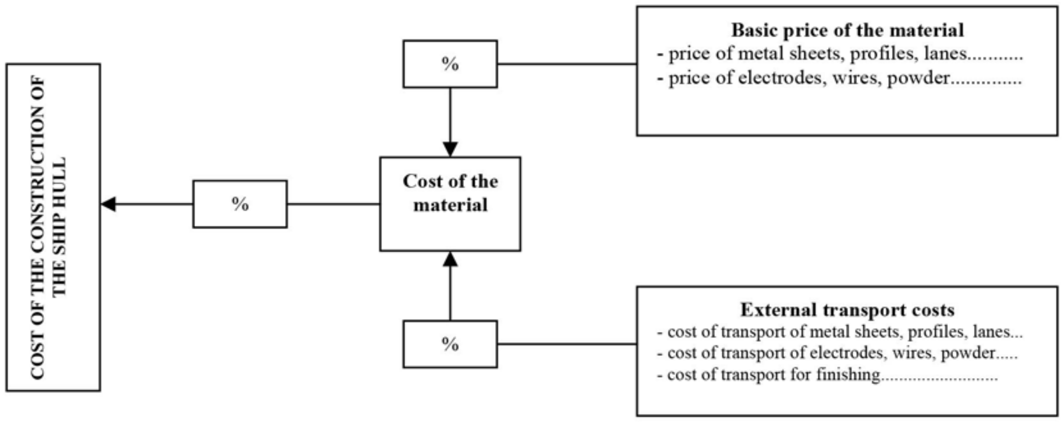

Figure 4 Structure of cost of materials within the cost of the construction of the ship hull

Source: Authors

Regarding that, shipbuilding production process need to have clearly defined place or element through which the costs of external transport are penetrated in it and how does this situation effects on internal transport cost, and total cost of the construction of the ship (Figure 3). As an integrator in interaction of external transport costs including total costs of construction of the ship hull, there is a cost related to materials (Figure 4). Total cost of the material includes two fundamental factors:

- Basic prices of materials,
- Cost of materials delivery (transport, manipulative….).

The Figure 4 showed the "channel" through which costs of external transport (transport costs for metal sheets, profiles, layers, electrodes, processing...) participate in costs of construction of the ship hull and the ship as a whole. Rationalization of any segment of external transport has costs effect on final price od the product, in other words – the ship. Furthermore, there is a strong interdependence within individual segments which indicated that, for example, the way of shipment of metal sheets significantly affected on costs of processing, which furthermore effects on activities within the shipbuilding production system which demands costs management from their beginning or from the start of external transport.

3.2. Estimation of internal transport costs for the construction of the ship hull

Activities within organization or internal transport activities represented the logical flow of activities outside of organization or external transport activities [12]. Traditional approach to business organization observed these activities as not connected and separated in terms of costs. Nowadays, business strategy overcame frames of physical understanding of organization.

In context of that, transport activities have been observed as inseparable whole [3]. First of all, stochastic approach provided more quality insight in materials flow from supplier to the end consumer (user) and also provided wider space for organization. Within this space, organization can correct its costs through shaping of more rational transport flows. Objectives of shaping of transport flows are following:

- Minimum costs of transport of materials in production flows,
- Minimization of time needed for completion of production flows,
- Minimization of surface needed for working space,
- Synchronization of materials movement including technological operations,
- Automation of materials flows partially or in the entire production process,
- Improvement of human conditions for development of production flows.

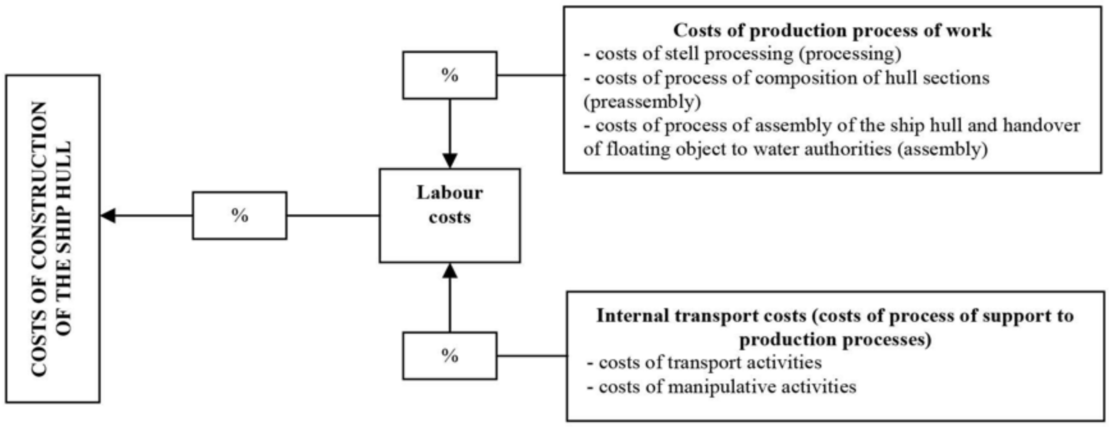

Figure 5 Structure of labour costs related to construction of the ship hull

Source: Authors

Clear defining of costs of internal transport activities is often difficult due to lack of their separation from total costs of individual operation or process. Therefore, it is important to determine places of modification of transport costs (places where transport costs transfer into other forms of costs), and their level of effect on following activities (Figure 5). The complexity of the shipbuilding process (shipbuilding system very often includes different forms of production processes) additionally highlighted importance of management of internal transport as a connection of all processes within the organization. Furthermore, internal transport activities whose efficiency is partially determined by quality of management functions within the organization, represented the indicator of success of business and competitiveness of the company.

3.3. Estimation of manipulative costs of raw materials in construction of the ship hull

Moving of material inputs in the shipbuilding process is a product in which manipulative activity has significant impact. Difficulty in costs analysis of this activity represented grouping of same activities within total costs of transport. However, the fact that manipulative activity as costs input significantly defined the price of material goods (cca 10%), sale price (cca 15%) imposes the need for their analysis separately from clear transport activities. Manipulative activities include numerous, complex, often very risky and expensive manipulations or operations such as following: packing, signing (marking), sorting, weighing, measuring, counting, loading and unloading, reloading, palletizing goods, warehousing, filling and draining of containers and transport vehicles [6]. From the perspective of manipulative costs made through construction of the ship hull, the largest amount is related to activities of loading, unloading and reloading of material goods. One of important characteristics of the transport-manipulative system for the shipbuilding process is the location where these activities are performed. Besides moving by road, certain activities also can be provided by sea flows while certain floating vehicles (floating cranes, barges...) for transport of different load are included.

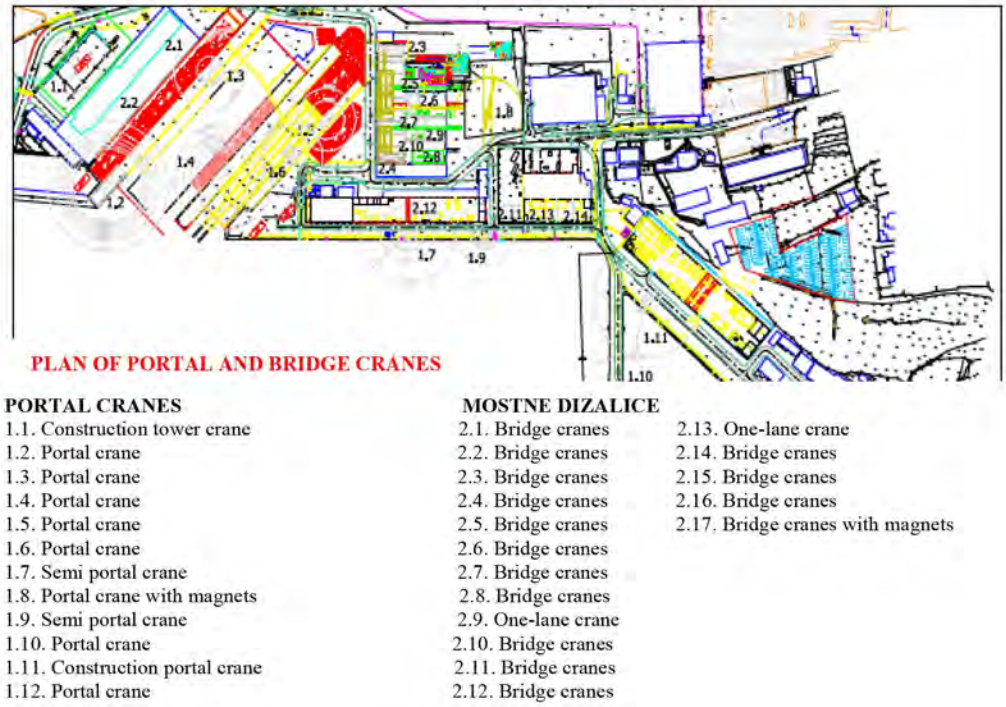

Figure 6 Types and spatial layout of cranes within the Brodotrogir Company

Source: Rovan et al., 2006

The Figure 6 presented the layout and types of all cranes provided by production system of the Brodotrogir Company. It includes various cranes with the load range between 2 t to 100 t. As working vehicles which provide 80 – 90% of manipulative activities for construction of the ship hull, cranes significantly determine the total costs of the construction related to the sale price of the ship.

3.4. Calculation of share of external, internal and manipulative costs for construction of the ship hull related to the sale price of the ship

Way of including of such costs in production process of the Brodotrogir Company differs by elements of integration (costs of materials and labour costs) and variables for their presentations. While external transport costs (using costs of materials as an integrator) can be considered as part of total costs for construction of the ship hull, internal transport costs and manipulative costs are "hidden" in labour costs.

- Share of external transport costs for construction of the ship hull within the sale price of the ship

External transport costs for construction of the ship hull are "hidden" in costs of materials as following:

- Costs for transport of metal sheets, profiles, lanes,…,
- Costs for transport of electrodes, wires, powder,...,
- Costs for transport of parts for reprocessing.

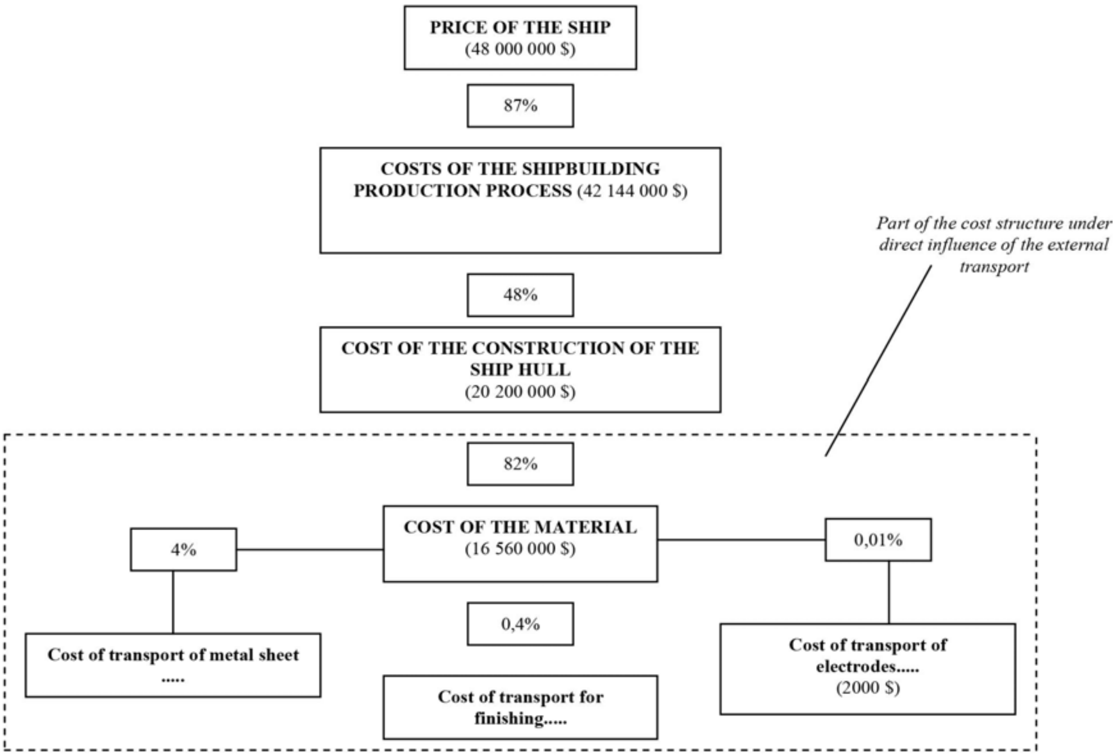

Figure 7 Share of cost of external transport for the construction of the ship hull within the price of the ship itself

Source: Authors

If processes which are basic for construction of the ship hull (processing process, process of preassembly and assembly process) can be excluded from the production part of the shipbuilding process, there is an opportunity for segmentation of share of external transport costs in total price of the ship, according to manner presented by the Figure 7.

- Share of internal transport and manipulative costs for construction of the ship hull in the price of the ship

Internal transport and manipulative costs are accumulated as activities of support to basic processes of the construction of the ship hull. They are presented as following:

- Process of steel processing (processing),
- Process of composition of the hull sections (assembly),
- Process of the hull assembly and handover of the object to water authorities (assembly).

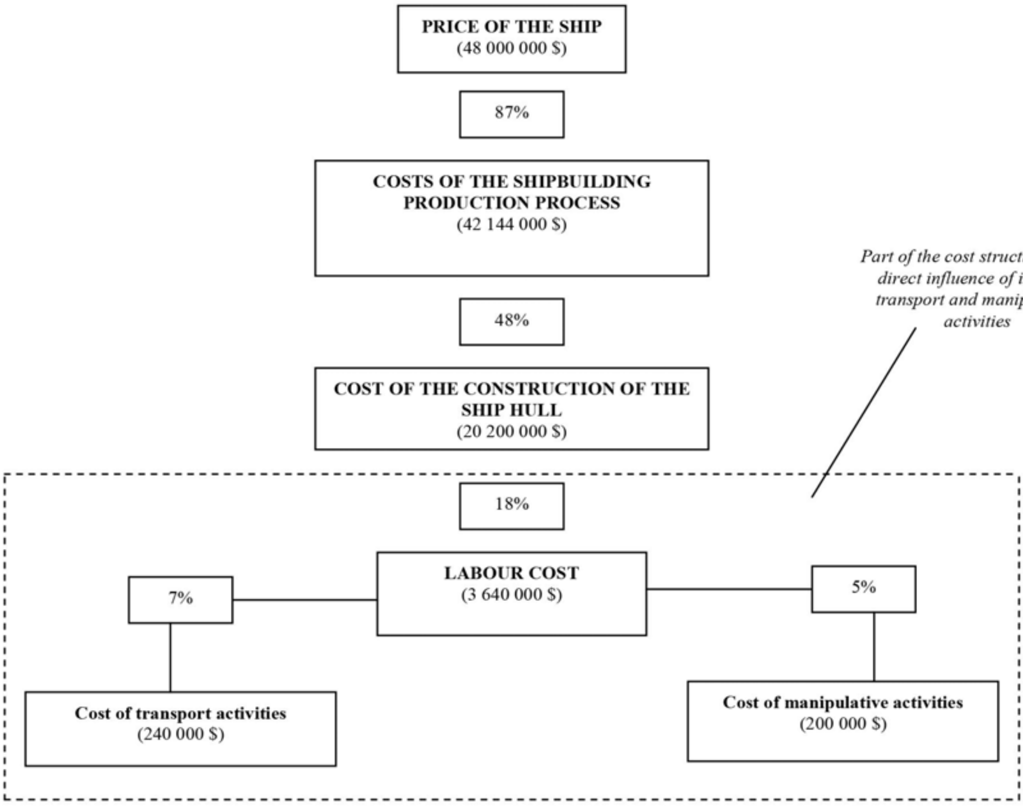

Figure 8 Share of cost of internal transport and manipulative activities for the construction of the ship hull within the price of the ship

Source: Authors

Costs of internal transport and manipulative activities are considered as integral part of total labour costs (Figure 8) which furthermore constitutes one of two main costs of the construction of the ship hull (labour costs and material costs). Rationalization within these activities using correlation capacities directly affected on costs efficiency of the entire shipbuilding production process.

4. RATIONALIZATION OF TRANSPORT AND MANIPULATIVE COSTS FOR THE CONSTRUCTION OF THE SHIP HULL

The development of model for rationalization of external, internal and manipulative transport costs for construction of the ship hull will firstly focus on the segment whose interaction most significantly determines the mentioned costs. The lack of means of work (benders for making of wrinkled - crowned partitions) significantly determined the logistic – distribution chain, within which external transport represented the important costs factor. The Figure 7 clearly indicated on large share of costs of transport of metal sheets, lanes and profiles related to total costs for materials (4%), needed for the production process of the construction of the ship hull. Specificity of this cost is also reflected in the fact that beside effects on internal transport and manipulative costs (Figure 8), it also partially defined external transport costs which are hidden in costs of transport for finishing.

Technological composition of making of wrinkled (crowned) ship partitions includes several characteristic phases – processes:

- Receipt of raw materials – metal sheets,
- Sandblasting and colouring,

- Rerouting (marking of reshaping spots),
- Bending – shaping.

All mentioned phases include certain rules which are directly connected to the level of technological development of the organization. Impossibility for separate conduction of the last phase (bending – shaping) in processes of making of wrinkled partitions demanded certain actions at the early phase of work (receipt of raw materials) in the Brodotrogir company. That fact makes this segment of the production process as appropriate for development of the simulation model. Also, it could be also useful for indicating of the importance of management of transport activities (synchronization of external and internal transport activities) for total competitiveness of the Brodotrogir Company.

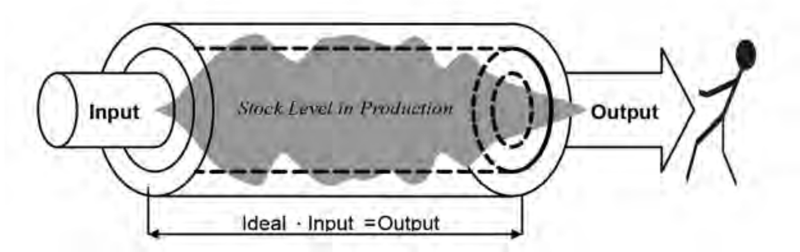

Figure 9 "Pulling" system as an organizational model of resources management

Source: Rovan et al., 1996

Extraction of certain technological processes (whether there is technological limitation or cost-effectiveness) from the technological system of the organization itself had significant impact on certain logical activities (procurement, transport, warehousing…). Therefore, it is important to approach systematically and to include all possibilities of cost-effective action. The aim of modern organizations is to provide pull systems (Figure 9) where end user will be able to "pull" needed resources (material, human…). In this way, the possibility of useless accumulation of the material, people and other resources can be minimized which can increase the competitiveness of the organization from the cost-effectiveness point of view [7]. External transport of delivery of metal sheets for the construction of the ship hull included the largest share (4%), and it had direct effect on costs of finishing, such as making of bended ship partitions for the Brodotrogir Company. The amount of metal sheets for making of ship partitions is 1375 t. Hence, their share in total costs is 16 % (600 000 $) of delivery of metal sheets for the construction of the ship hull. Therefore, due to existing subjective and objective limitations which the Brodotrogir Company is faced with, delivery of metal sheets had greater effect than mentioned direct costs. Direction through which metal sheets are delivered largely determined the costs structure of manipulative and transport activities. Therefore, it is important to clarify manipulative and transport activities in order to choose the most rational and cost effective among them.

4.1. Simulation of transport and manipulative costs of making of impermeable partitions of the ship hull

Technology limitations of the Brodotrogir Company regarding impermeable partitions of the ship hull determined transport and manipulative costs. Transport directions for delivery of needed raw materials (metal sheets) can be highly important for total production costs of partitions themselves and final product (chemical tanker). This fact profiled two possible transport directions of the delivery of raw materials for making of impermeable partitions for which the costs simulation will be provided in order to determine their economic effectiveness. Delivery of metal sheets via route Skopje – Thessaloniki – Trogir (Figure 10) includes several specificities which are defined by needed activities in process of making of impermeable partitions at the Brodotrogir Company. Impossibility for processing of metal sheets by bending, which is demanded by technological process of making of impermeable partitions, created higher costs in production process of the Brodotrogir Company.

- Simulation of transport and manipulative costs of the delivery of metal sheets for the construction of the ship hull at the route Skopje - Thessaloniki – Trogir

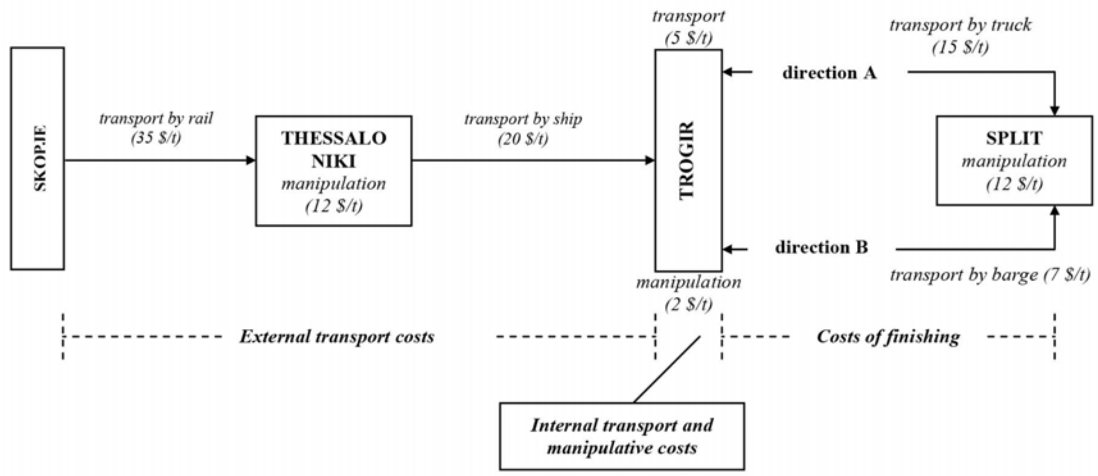

Figure 10 Structure of transport and manipulative costs of delivery of metal sheets for making of impermeable partitions of the ship using route Skopje – Thessaloniki – Trogir

Source: Authors

Certain actions before the bending process can be conducted at the shipyard (sandblasting, trimming, rounding off etc.) and that can justify the delivery of metal sheets through transport route Skopje – Thessaloniki – Trogir. Direct monitoring of this process at the shipyard can help in avoiding of possible important problems which can appear during the installation of impermeable partitions (non-precise dimensions) and further more create additional costs to total costs of the final price of the ship. Such costs can be expressed through afterward adaptation of partitions during installation which leads to increased number of working hours needed for centering, drilling and welding. Conduction of these activities at the shipyard do not delay control during the technological process of bending of metal sheets at the Brodosplit company. Costs of controlling outside the process itself needs to be calculated in costs calculation through which the selection of transport direction can be estimated. Delivery of metal sheets for making of impermeable partitions in the Brodotrogir company also increased internal transport and manipulative costs. Activities of transport and manipulation demanded higher engagement of human resources and means of work (coastal cranes, hydraulic transporter, magnetic crane, etc.). Pricing in ports is an important element of competitiveness when it comes to the establishment of logistics and transportation systems, determining cargo flows, and developing optimum and quality service [10].

Engagement of new capacities provided possible redirecting or decreasing of the intensity of activities in other production processes within the shipyard. After all activities conducted before bending of metal sheets, all of them needs to be transported to the place of the technological process. Geographical location where processing of metal sheets will be done (the Brodosplit company) provides transport by road or by the sea waterways (Figure 11). Road transport includes outsourcing of transport vehicle so the intensity of repetitions might be higher due to vehicle itself and road infrastructure (permitted weight of the loaded vehicle while going over moving bridge which connects island Čiovo with Trogir is limited to 25 t for security reasons). Regarding transport by the sea waterways, intensity of repetitions is smaller because of capacities of the transport vehicle (barges have the capacity between 1000 – 1500 t). However, there is a need to outsource more barges and to obtain certain maritime permits. It is important to highlight that the intensity of repetitions also leads to higher manipulation costs regarding activities of loading and unloading. Choosing of the route Skopje - Thessaloniki – Trogir for delivery of metal sheets in order to make impermeable partitions provides higher control over preparation activities (sandblasting, trimming etc.) which significantly decreases possibilities for appearance of costs during phase of assembly of metal sheets (centering, welding, grinding, etc.). However, negative effects to costs while using this route can be expressed through increased intensity of transport and manipulative activities. Furthermore, engagement of certain means of work and human resources can have effect on dynamics of other shipbuilding processes. Including numerical values, i.e. quantities of 1375.00 t plates for making watertight bulkheads in the shown simulation model of transport and handling costs (Figure 10), shows that choosing direction A costs $ 159,500.00, while choosing direction B costs $ 137,500.00. It is evident that choosing direction B saves $ 22,000.00.

- Simulation of transport and manipulative costs for delivery of metal sheets for the construction of the ship hull using the route Skopje - Thessaloniki - Split

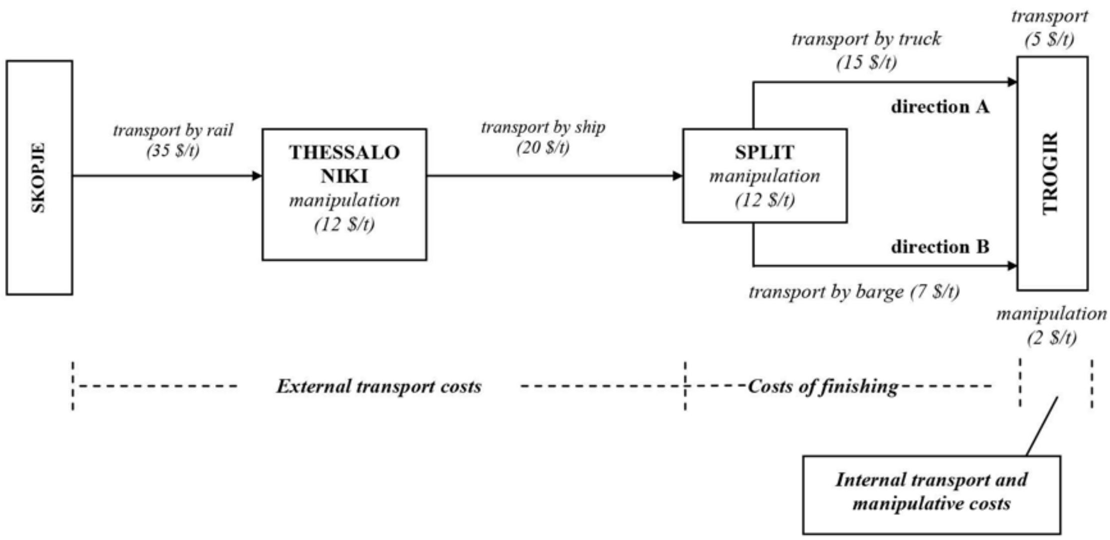

Figure 11 Structure of transport and manipulative costs for delivery of metal sheets for making of impermeable partitions for ship, via route Skopje – Thessaloniki – Split

Source: Authors

The second possible transport direction for delivery of metal sheets is the route Skopje – Thessaloniki – Split (figure 11) which determines certain transport and manipulative activities. Using of this route provides possibility to avoid certain manipulative and transport costs but also to increase the risk from appearance of mistakes during assembly of impermeable partitions. External transport and manipulative costs generated on the route Skopje – Thessaloniki – Split are identical to costs at the route Skopje – Thessaloniki – Trogir which originated from the geographical position of two final destinations (road distance between Split and Trogir is cca 25 km). Including numerical values, i.e. quantities of 1375.00 t plates for making watertight bulkheads in the shown simulation model of transport and handling costs (Figure 11), shows that choosing direction A costs $ 132,000.00, while choosing direction B costs $ 121,000.00. It is evident that choosing direction B saves $ 11,000.00. The analysis of both offered simulation models of transport and handling costs of supplying metal plates for the construction of watertight bulkheads reveals a significant difference in the most favorable directions of one and the other offered model, and it amounts to $ 16,500.00.

This fact has a significant impact on cost effectiveness of choosing of Split as a final destination during the transport of metal sheets for making of impermeable partitions. It can be observed through following:

- Decreasing of internal transport and manipulative costs,
- Decreasing of intensity of transport of final (finished) product,
- Decreasing of costs caused by reducing of dynamics of production process due to engagement of means of work and human resources.

Possibility of increased costs expressed through higher amount of working hours for activities related to centering, welding and grinding during the assembly (of impermeable partitions) appears as a negative consequence of this selection. Furthermore, it is important to include and conduct external control of preparation activities which also can increase total cost of making of these elements.

5. CONCLUSION

Among all industry areas, especially in industry of metal processing, transport is one of the most significant functions since it connects all production – technological segments through transport, removing and transferring of materials (raw materials, objects and products) within spaces and objects of the industrial company. The mutual feature of all kinds of production is need for handling material in order to achieve higher efficiency, economy and humanization of work. The strong development of production capacities in all areas of economy demanded accelerated application and development of transport technique whose numerous devices make component part of production chain of technological process. Transport of materials has the special place in industry because its efficiency has significant impact on level of profitability and success of working organization as a whole. The transport is especially important in production areas of the shipbuilding construction since it provides connection between individual production processes. In other words, it facilitates manipulation of materials. Shortening of the time for work and transport costs provide significant costs savings and lowering of the price of the product. Since fast and cheap transport provides increasing of profitable availability of different physical resources, it also impacts on increasing of other nonmaterial factors of the production, especially knowledge and special skills of well trained workers. Many elements define forming of transport directions or in other words, they impact on tendencies of moving of goods using traffic and economy, kind and elements of forming of flows for goods. Regarding that, transport routes are not a static phenomenon in space and time. Actually, they are a dynamic phenomenon which is affected by numerous elements regarding its forming, layout and intensity.

One of the key factors in the formation of transport routes is the degree of technological development of an organization, which is directly correlated with the price of the final product. In this paper, an analysis of the optimum transportation direction of the plates required for the production of leakproof bulkheads was carried out as a key element in Brodotrogir Shipbuilding Process. With regard to the technological inability to form plates and to make sealed bulkheads, Brodotrogir is obliged to choose the optimum transport directions with the aim of combining cost and production efficiency. During the cost analysis, two potential directions for the supply of plates (Skopje - Thessaloniki - Trogir and Skopje - Thessaloniki - Split) justified the use of the direction of Skopje - Thessaloniki - Split. The choice of this direction was significantly influenced by the technological limitation of the Brodotrogir and the costs of preparatory work on sheet metal processing (sandblasting, coating, etc.) that need to be done before the final product is formed (leakproof bulkhead). In addition to technological weaknesses, the analysis also pointed to the importance of business environment development, ie transport infrastructure and business entities, competitiveness and efficiency of manufacturing organizations such as Brodotrogir. All this points to the need for a thorough understanding of the interdependence of primary production processes and auxiliary processes such as transport, which largely shape the overall competitiveness of the complex world market. Speed and adaptivity become key factors for the sustainable development of every company, including shipyards such as Brodotrogir.

REFERENCES

[1] Bloomberg, J.; LeMay, S.; Hanna, B. (2006) *Logistika*. Mate. Zagreb, Croatia

[2] Christopher, M. (2005) *Logistics and Supply Chain Management*. Prentice Hall

[3] Ferišak, V. (2006) *Nabava – politika, strategija, organizacija, management*. VF. Zagreb, Croatia

[4] Schroeder, R. (1999) *Upravljanje proizvodnjom*. Mate. Zagreb, Croatia

[5] Segetlija, Z. (2008) *Uvod u poslovnu logistiku*, Faculty of Economics in Osijek, Croatia

[6] Rovan, M.; Geić, M. (2006) *Tehničko – tehnološka opravdanost restrukturiranja Sektora Brodogradilište*. Studija, Brodotrogir d.d., Trogir, Croatia

[7] Rovan, M.; Veža, I. (1996) *Proizvodni sustavi*. Teaching material. Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture in Split, Croatia

[8] Stanivuk, T.; Tokić, T.; Šoškić, S. (2013) *Transport Costs Affecting LNG Delivery by Moss Type Carriers*. Scientific journal Transactions on Maritime Science. Vol. 2. No 1. pp. 36-40

[9] Vidan, P.; Stanivuk, T.; Bielić, T. (2012) *Effectiveness and Ergonomic of Integrated Navigation System*. Scientific journal Transactions on Maritime Science. Vol.1. No 1. pp. 17-21

[10] Vukić, L.; Peronja, I.; Slišković, M. (2018) *Port Pricing in the North Port of Split: A Comparative Analysis*. Scientific journal Transactions on Maritime Science. Vol. 7. No 1. pp. 59-70

[11] Zelenika, R. (2005) *Logistički sustavi*. Faculty of Economics and Business in Rijeka, Croatia

[12] Zelenika, R.; Pupavac, D. (2008) *Menadžment logističkih sustava*. Faculty of Economics and Business in Rijeka, Croatia

MAINTENANCE PROCESS ADJUSTMENT BASED ON COMPUTERIZED PMS DATA

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Summary

In order for machines and devices to work properly during a long period of exploitation, it is necessary to have an adequate maintenance plan. The initial maintenance schedule for each machine is created by the manufacturer, using their knowledge and experience in operation with this device. Maintenance recommendations were made for all devices of this type; the manufacturer could not foresee all the conditions under which the device would operate. During the lifetime of a device, it is possible to modify a maintenance plan, taking into account the conditions in which the device is operating. Planned maintenance systems must be able to keep all maintenance records. By systematically analysing this data, after a sufficiently long period of exploitation, it is possible to suggest modifications to adapt the initial maintenance plan to the operating conditions of that device. In doing so, the modifications must not affect the performance and safety of the ship. The maintenance plan adjustment using data from the Planned maintenance system is shown in the example of the engine room fan system consisting of four centrifugal fans. The fans work independently of each other and provide air for engine room machinery. Maintenance of the fan system is included in the computerized Planned maintenance system. It is keeping records of previous maintenance, which, after a sufficiently long period of time, provide sufficient data for analysis, i.e. for the calculation of reliability. Changes to the maintenance plan which will improve the maintenance system can be based on that calculation.

Keywords: Planned Maintenance System, database, reliability, maintenance adjustment, fan system

1. INTRODUCTION

"*Although the first appearance of Planned Maintenance System is not recorded, it is known that the system is in use in the shipping industry for over one hundred years*" [1]. Computerized Planned Maintenance Systems appeared at the same time as the mass use of the computers began and "*have been in use for more than thirty years in the shipping industry*" [2]. Since then, computer programs have mostly replaced written systems for planned maintenance and are used to assist in the planning and execution of maintenance of various machinery and devices, as well as for keeping records of maintenance performed. Those records are easily sortable and accessible and can be a source for analysis and failure checking. ''*Analysis and failures can be used to determine the reliability and risks in detail and to adjust the maintenance system, taking into account cost and reliability*'' [3]. Using a computerized Planned Maintenance System makes maintenance monitoring simpler and better, allows easy and quick modifications of the maintenance plan, as well as better supervision of the implementation and results of a new maintenance plan.

The engine room fan system is described as a showcase in this paper. It is one of the ship's auxiliary systems, necessary for normal operation of machinery and equipment in the engine room. It consists of several fans working independently of one another, which is the most common configuration of the system [4].

The maintenance plan within the planned maintenance system was created from three main sources:

- Recommendation of the manufacturer [5], [6],
- Rules and regulations, e.g. classification societies [7],
- Shipowner's experience built in the company's SMS (Safety Management System) [8].

Maintenance data of the engine room ventilation system maintenance is taken from the computerized Planned Maintenance System. Reviewing the multi-year maintenance records and analysis the data has created a conclusion on the quality of maintenance.

Following the results of the analysis of the maintenance records data, it is possible to modify the maintenance plan with the aim to:

- Increase system reliability by a decrease of unplanned maintenance, or
- Decrease maintenance costs in case of maintenance period increase, as in this showcase.

1.1. Non-disclosure condition

As the shipping company allowed access to their database and real data strictly under no disclosure condition, all data leading to the identification of the ship and the company is removed from screenshots and figures.

2. ANALYZED SYSTEM AND MAINTENANCE DATA

Analysed system consists of four identical electric motors driven fans (Figure 1), the only difference between them is that fans No2 & 4 are reversible.

SYS No.	USE	SUPPLY ITEM	WEIGHT (kg/SET)	Q´ty /SHIP	TOTAL WEIGHT (kg)
S-21	No. 1 ENGINE ROOM SUP. (RV. NON-REV.)	VENT. FAN with MOTOR (AQ - 1250)	820	1	820
		HEX. BOLTS & NUTS (SUS304, M20x60L)	-	40	-
		HEX. BOLTS & NUTS (SUS304, M20x65L)	-	20	-
		RUBBER PACKINGS (5t, ø1250)	-	3	-
		ANTI-VIB. PACKING (AVP - 1250)	-	20	-
BLOCK No. : M310A		FAN SEAT (FSV - 1250)	69	1	69
		INLET CONE (ICW - 1250)	135	1	135
		MULTI–BLADE ROUND CLOSING DAMPER (CDRB – 1250)	350	1	350

Figure 1 ER fan data

Source: [6]

"The amount of air required for ventilation is calculated in relation to the amount of heat to be taken and the amount of combustion air depends on the power of the plant" [4]. System data requires that two fans should operate in the supply mode for normal operation to the engine room during navigation (Figure 2).

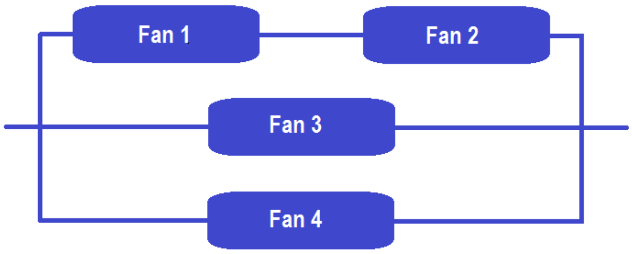


Figure 2 Fan system working configuration

2.1. Initial maintenance plan

The fan maintenance plan consists of four jobs that are periodically performed:

- The fan and electric motor check in operation, the vibration and sound check have to be performed every three months.
- Measurement of Electric motor winding resistance (Megger test) and visual check to be performed every three months.
- The fan and electric motors inspection include a fan inspection without disassembly, checking the screws and housing and the overall condition of the electric motor. This job is performed every 5000 hours. In the case of noted deficiencies during the inspection, an overhaul should be performed and an overhaul job should be written in the Planned Maintenance System.
- The fan overhaul is performed every 20000 running hours and includes bearing renewal and windings cleaning, while the renovation of the winding insulation depends on the condition.

2.2. Fan overhauls

As the Overhaul of the fan and motor is performed and reported into the PMS in case of a fan failure, therefore during the analysis of fan system maintenance, only this work will be analysed.

Only one corrective overhaul entry is recorded in the Computerised Planned Maintenance program for the system (Figure 3) during a period of ship exploitation.

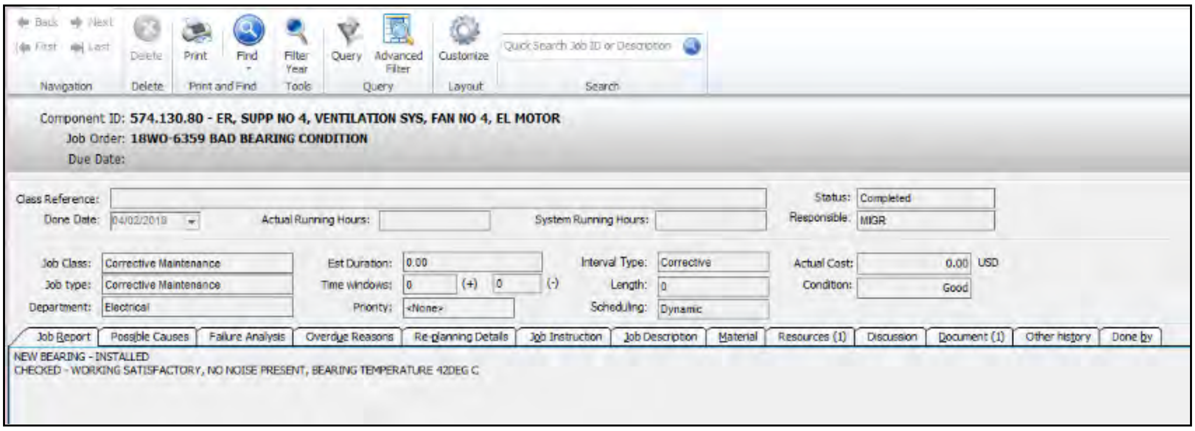


Figure 3 Corrective overhaul entry in the Computerised Planned Maintenance program

Data about the overhaul of the Engine room ventilation fans and motors are collected from the PMS system and converted in Table 1.

Table 1 Fan and motor maintenance history

	Description	Job type	Date (yy/mm/dd)	Running hours
Fan No. 2	Overhaul of Fan and motor	Overhaul	2014/07/14	8744
Fan No. 4	Overhaul of Fan and motor	Overhaul	2015/06/16	15886
Fan No. 3	Overhaul of Fan and motor	Overhaul	2016/06/12	23487
Fan No. 1	Overhaul of Fan and motor	Overhaul	2017/04/03	34847
Fan No. 4	Overhaul of Fan and motor	Overhaul – corrective	2018/02/04	38413

2.3. Fan running time

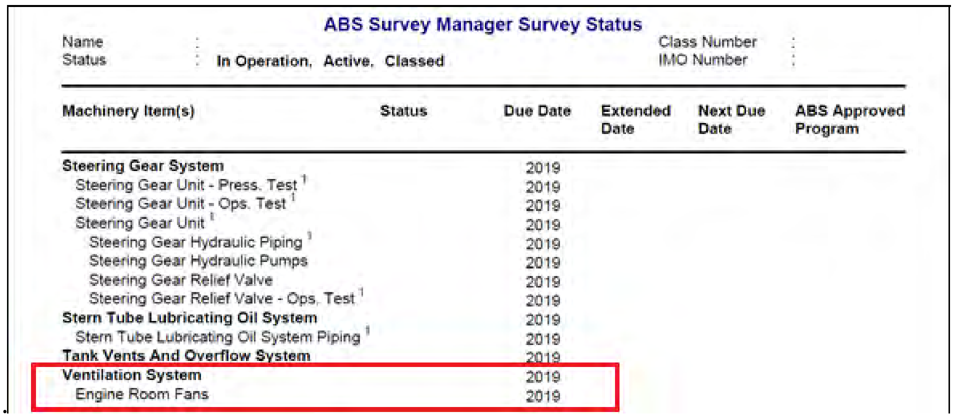
Total running hours for all four fans are taken from the computerized PMS program (Table 2). The average annual running hours are calculated using the date of ship delivery (3rd May 2013).

Table 2 Fan running time

Fan	No. 1	No. 2	No. 3	No. 4	All
Running hours	23163	22986	22732	23977	92858
Average daily	13.1	13.0	12.9	13.6	13.2
Average annual	4798.2	4745.4	4709.0	4950.0	4808.9

2.4. Class requirements

Classification societies, members of IACS, such as ABS [7], require maintenance of the ER fans to be performed at least every 60 months (Figure 4).


ABS Survey Manager Survey Status

Name :
Status : In Operation, Active, Classed
Class Number :
IMO Number :

Machinery Item(s)	Status	Due Date	Extended Date	Next Due Date	ABS Approved Program
Steering Gear System		2019			
Steering Gear Unit - Press. Test 1		2019			
Steering Gear Unit - Ops. Test 1		2019			
Steering Gear Unit 1		2019			
Steering Gear Hydraulic Piping 1		2019			
Steering Gear Hydraulic Pumps		2019			
Steering Gear Relief Valve		2019			
Steering Gear Relief Valve - Ops. Test 1		2019			
Stern Tube Lubricating Oil System		2019			
Stern Tube Lubricating Oil System Piping 1		2019			
Tank Vents And Overflow System		2019			
Ventilation System		2019			
Engine Room Fans		2019			

Figure 4 ABS Survey Items

Source: [7], Confidential data (name, dates and numbers) have been removed from the figure!

According to the data from Table 2, ER fan no 4 has a maximal number of running hours, 4950 annually. In five years, this fan will run for 24750 hours. According to this calculation, the required (five yearly) maintenance in line with the Class requirements would take place every 25000 running hours (or close to).

3. MAINTENANCE DATA ANALYSYS & MODIFICATION PROPOSAL

Analysis of the maintenance data is performed using a random failure reliability calculation. Reliability calculation is made according to Equation 1, using the data from Table 3.

$$R = e^{-\lambda t} \tag{1}$$

Table 3 Failure rate and mean time between failures

Total number of running hours	t = 92858 [h]
Number of failures	n = 1
Failure rate	$\lambda = \frac{n}{t} = 10{,}76913 * 10^{-6}\ [h^{-1}]$
Mean time between failures	$m = \frac{1}{\lambda} = \frac{1}{10{,}76913 * 10^{-6}}\ [h]$

Redundancy of the system is taken into consideration, therefore, the reliability of the configuration from Figure 1 can be calculated:

$$R_{sys} = 1 - [(1 - R_1 * R_2) * (1 - R_3) * (1 - R_4)] \tag{2}$$

The calculated Reliability of the system is shown in Figure 5.

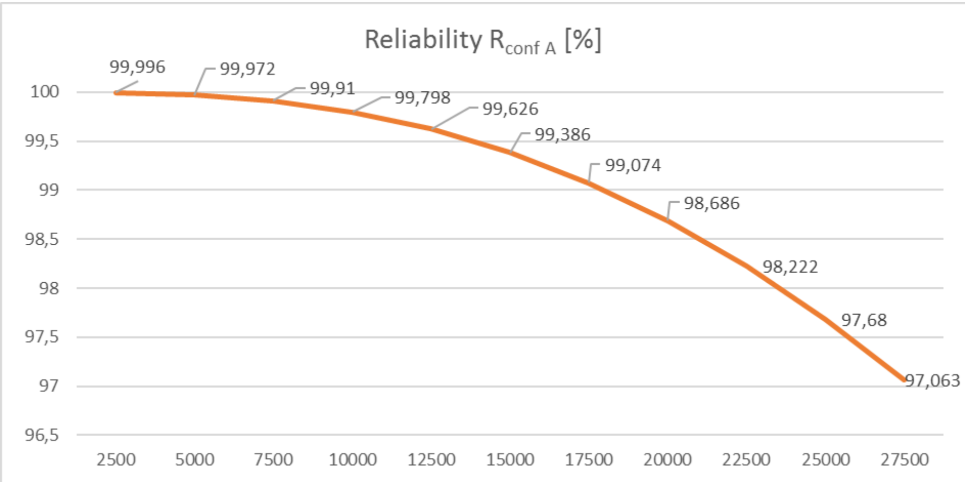


Figure 5 Reliability curve of the analysed system

3.1. Proposed Maintenance Plan modification

Reliability analysis showed that the system has high reliability, greater than 98.6% at the moment of an overhaul (due to the limited size of the analysed system, received results can deviate from the results of similar systems [9], [10]). The result suggests the possibility to increase the maintenance period. The increase of the maintenance period of the Overhaul is limited by Class requirements to 25000 running hours and 60 months, according to the calculation performed in Chapter 2.3 and 2.4. The proposed increase of the maintenance period will have a minor impact on the overall reliability (Figure 5), with a decrease of 1% at the end of the maintenance period.

Therefore, the maintenance plan modification proposal is:

- The maintenance period of the Overhaul job should be increased from 20000 to 25000 running hours, according to the calculation in Chapter 2.4.
- The same job should be triggered by the additional criterion of 60 months, which will be triggered if a fan did not run 25000 hours in 5 years.

4. POTENTIAL EFFECT OF THE MODIFICATION

The effect of the modification is an economic benefit, and it can be divided into several parts:

- Reducing the cost of personnel for the job,
- Reducing the cost of spare parts,
- Reducing the cost of consumables,
- Decreasing the costs of ordering, supply and storage of articles.

Reducing the cost of personnel for the job must be achieved without affecting the salary which on average is 4000-5500 $ for qualified electrician [11], or middle salary of 18.75 $ per hour. The duration of the electric motor overhaul, which is a main part of the fan overhaul, is estimated to 55.6 man-hours [12]. Multiplying man hours with a salary per hour and the number of units, overhaul costs of all four fans is 4170 $.

The cost of spare parts, i.e. the cost of the pair of the roller bearings 6318C3 and 6316C3, purchased directly from the manufacturer is about 340 $ (from the company purchasing department). Costs for all four fans is 1360 $.

The cost of consumables and the costs of ordering, supply and storage of articles is variable for every single case and will not be analysed here.

The average number of running hours is 4808.9 yearly (Table 2) and fans should be overhauled every 20000 running hours or 4.16 years. If the above amounts are divided over a greater period, considerable savings can be achieved (Table 4).

Table 4 Overhaul costs and savings

	Overall costs	Annual costs for 4.16 years overhaul / 20000 hrs. overhaul	Annual costs for 5 years overhaul / 25000 hrs. overhaul	Savings
Working costs	4170 $	1002,40 $	834 $	168,40 $
Spares cost	1360 $	326,92 $	272 $	54,92 $
Total	5530 $	1329,33 $	1106 $	223,33 $

3. CONCLUSION

The paper described the utilization of the computerized PMS data as the main source for the modification of the maintenance plan. Maintenance data written into computerized PMS after 5 year period provided enough data to perform maintenance analysis based on the calculation of the system reliability. The result of the system analysis showed the possibility for the modification of the ventilation system maintenance plan, i.e. in this case to increase the maintenance period. The increase of the maintenance period would not have a greater impact on the system's reliability, while calculated budget savings would be over $ 200 per year. Further increase of the maintenance period on this system would not be possible due to the restrictions of Classification Societies.

Calculation of reliability, based on data obtained from a Planned Maintenance System, is a good foundation for changing maintenance plans. That is a good method to steer the planned maintenance towards the reliability-based maintenance settings. Adjustment of the maintenance period should be associated with the systematic analysis, both before and after the procedure, to monitor the effects. The accuracy of the analysis will increase as time goes by and by an increase in the number of systems analysed.

The engine room ventilation represents a small segment of the ship's machinery, which consists of a large number of such systems. Adjusting the maintenance plan of this segment, with no major impact on system reliability, brought maintenance savings of around $ 200 a year. Therefore, the potential financial benefit of modifying the maintenance of the whole ship's machinery system is more than considerable.

REFERENCES

[1] Stazić, L., Komar, I., Mišura, A., Bukljaš Skočibušić, M. (2018). "Simplification of evaluation methodology for ship's PMS database", 18th International Conference on Transport Science - Conference proceedings, ISBN 978-961-7041-03-3, pp 346-351.

[2] Knežević, V., Stazić, L., Orović, J., Mihanović, L. (2019), "Use of PMS Continuous Improvement Scheme for Maintenance Adjustments in Shipping Industry", 8th International Maritime Science Conference (IMSC 2019), Book od Proceedings, pp. 415-420, ISBN: 978-86-80031-64-4.

[3] Vučinić, B., (1994), "MA – CAD, Maintenance concept adjustment and design", Delft, Faculty of Mechanical Engineering and Marine Technology.

[4] Babicz, J., (2015). "Wärtsilä Encyclopedia of Ship Technology", Second Edition, Helsinki 2015, ISBN 978-952-93-5536-5

[5] Hyundai Heavy Industries, (2010). "Instruction manual for three phase low voltage induction motor", Hyundai Heavy Industries Co. Ltd. - Electro-Electric System Division.

[6] Hyundai Heavy Industries, (2007). "Ventilation fans for machinery outfitting space", Hyundai Heavy Industries Co. Ltd.

[7] ABS.: URL: https://ww2.eagle.org/en.html, (accessed 18th May 2019)

[8] International Maritime Organization, (2015). Revised ISM Code, IMO, London, United Kingdom.

[9] Tversky, A.; Kahneman, D., (1971), "Belief in the law of small numbers", Psychological bulletin, Vol 76 No 2: pp. 105-110.

[10] Dobrota, Đ. (2017). "Modeliranje distribucije priora u analizi kvarova brodskih hidrauličkih uređaja", doctoral dissertation, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split.

[11] Cruise Ship Jobs, URL: http://www.cruiseshipjob.com/electrician-jobs.html (accessed 2nd June 2019)

[12] Oreda Participants, (2002): "Offshore Reliability Data Handbook", Fourth Edition, Det Norske Veritas.

MODELLING AND EXPERIMENT OF A FIN FOR BIOMIMETIC UNDERWATER VEHICLE

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Summary

In this paper the simulation model of a one-piece inflexible fin acting in the water environment is presented. The fin is designed for the propulsion system in a biomimetic underwater vehicle (BUV). The research are focused on the fluid structure interaction. For the verification of the simulation results the laboratory water tunnel was designed and equipment with the specialized sensors for force measurements and control of the fluid velocity. The average value of fluid velocity in water tunnel was measured by specialized high accuracy ultrasonic flowmeter. For the analysis of a turbulent and a laminar area in contact space between the fin and a fluid the vision system was applied. A results from vision system are depicted with the description of the algorithm used. The aim of the research is make a useful model for optimization of the BUV propulsion system. It is going to be done by investigation of the laminar and turbulent flows in fluid structure interaction areas. Considering the complexity of phenomena and nonlinearity of the characteristics, a dimensional analysis was adopted to determine the mutual, selected relationships between the fluid velocity and the drag force.

Keywords: artificial fish, fluid structure interaction, computational fluid dynamics (CFD), biomimetic underwater vehicle

1. INTRODUCTION

The Biomimetic Underwater Vehicles BUVs can be used in a wide variety of underwater applications [5], such as monitoring [4], investigation of sea region [18], pollution detection, military operation and protection [18], [21]. In comparison to the propulsion systems with rotary propeller the energy efficiency is limited to 70 % and is 20 % less than the swimming mechanism of real fish [8], [13],[15], [15]. The biomimetic underwater vehicles (Figure 1) are more popular due to their advantages like: a high-performance locomotion and maneuvering in the water, a secrecy of operation due to the lower acoustic spectrum. The different kind of fish results from the longtime of fish evolution. The body motion function of a specific swim pattern is generally obtained from biologists [9], [13], [22]. The fish like movement can be reproduced with fin made from flexible material or as a connection of rigid body with number of degrees of freedom depends on a specific swim pattern [11], [12], [19]. Many links needed to accurately reproduce fish behavior makes robot model complex and its control techniques more complicated. Therefore, efforts are to be made to imitate the movement of fish with one piece of flexible fin [20]. This provides to investigation of the fluid-structure interaction phenomena which is depending on many construction factors.

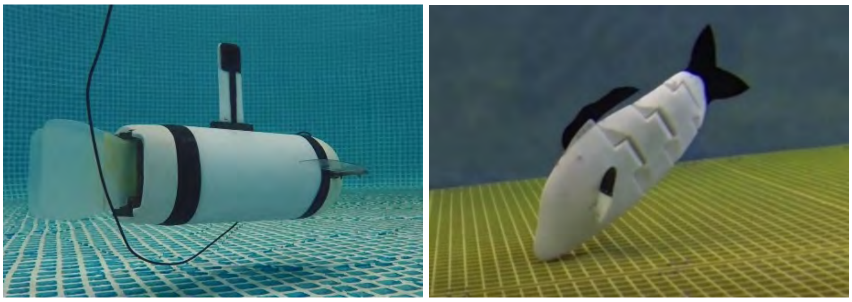


Figure 1 The Biomimetic Underwater Vehicles: miniCyberSeal (left photo) [20], CyberFish (right photo) [15]

Source: [20],[15]

Due to the nonlinear fluid-structure interaction the following method was applied. At the beginning, the fluid without any obstacles was measured using Particle Image Velocimetry (PIV) method. Then, examples with a cylinder were considered for verification of drag force calculations. Having done the calibration of the laboratory equipment the experiment for the fin was elaborated. The velocity region with a laminar and a turbulent flow was identified and the force for different angle of attack was measured. The angle of attack is understood here as the angle between the fin and the fluid stream.

At the beginning of the paper, the dimensional analysis was presented. Then simulation model was depicted with numerical simulation results made in LS-DYNA package and Incompressible Computational Fluid Dynamics (ICFD) solver. The simulation model was verified in the laboratory test stand equipped with force measurement system and the vision system. At the end of the paper, the discussion was provided in connection to further research on the fluid structure interaction in the undulating propulsion system.

2. SIMULATION MODEL

The dimensional analysis was conducted according to the Buckingham theory [11]. The functional relationships between the variables involved in a physical phenomenon are independent of the chosen system of units. The principle allows to express all the information contained in the relationships between physical variables of the problem in a very compact form, using a reduced number of dimensionless variables. It reduces the number of measurements and numerical simulations needed to characterize a specific flow problem.

The analyzed problem is a steady flow of an incompressible fluid of density ρ and viscosity μ around the cylinder with radius R (2D phenomena). The second analysis was for the inflexible fin mounted on the motor shaft (2D analysis) [11]. The fin angle was changed in a range compared to the fish tail movement.

Since the incompressible flow is analyzed it can be assumed that the equation of a continuity and a momentum can be decoupled from the equation of an energy, and the equations are needed to determine the pressure and the velocity fields. The force over the body involves surface integrals made up with the pressure and the velocity fields, that is why only the continuity and the momentum equations have to be considered. In addition, because the problem is analyzed as a steady one, no initial conditions are required. With respect to the boundary conditions, the flow filed far away from the cylinder needed to be specified. The next assumption is connected with a velocity and a pressure. The far field fluid velocity relatively to the body is aligned along the *x* direction, and the far field pressure takes a uniform value.

According to the Pi theory the number of independent and dependent variables should be defined. Since there is steady state problem the time is not taken under consideration. The independent variable is a spatial variable. While the dependent variables are velocity and pressure. The drag force (F_d) exerted by the fluid on an analyzed object (the cylinder or the fin) depends on a surface, a density, a viscosity and a fluid velocity. The expression defining the drag force can be written as:

$$F_d = f\ (\rho, \mu, U, A) \tag{1}$$

where:

U - is the far field fluid velocity

The dimensions of the magnitudes μ, F_d, can be expressed in terms of the dimensions of ρ, A and U as following formulas:

$$\begin{gathered}[F_d] = [\rho][\mu][U^2][A^2] \\ [\mu] = [\rho][U][A]\end{gathered} \tag{2}$$

According to the Buckingham theory, there is $n = 4$ and $k = 3$ and consequently the number of dimensionless parameters linked to the original expression is $n + 1 - k = 2$. These two parameters are constructed to transform μ, F_d into dimensionless variables using ρ, U, A.

Thus:

$$\begin{gathered}\Pi_0 = F_d/(\rho U^2 A^2) \\ \Pi_1 = (\rho U A)/\mu\end{gathered} \tag{3}$$

Next, writing in the non-dimensional form the next formula can be written:

$$F_d/(\rho U^2 A^2) = f(\rho U A/\mu) \tag{4}$$

where:

$\rho U A/\mu$ - is the flow Reynolds number;

$F_d/(\rho U^2 A^2)$ - is the dimensionless parameter π_0 proportional to the drag coefficient C_d, defined as:

$$C_d = F_d/\left(\frac{1}{2}\rho U^2 A\right) \tag{5}$$

where:

A - is a frontal area of the obstacle exposed to the flow. In the case of the cylinder, the frontal area is $A = 2Rh$, where h is the height of the submerged part of the cylinder. The frontal area for a fin depends on the angle of attack according to the formula: A = length*cos(α), where: α – is the angle of attack.

It can be seen that the drag force coefficient only depends on the Reynolds number. Therefore, during simulation and measurements, the Reynolds number was changed by the different fluid velocity and by different characteristic dimensions (the radius of the cylinder or the fin angle of attack).

To carry out the numerical simulations LS-DYNA Incompressible Computational Fluid Dynamics (ICFD) solver has been used. The modern and efficient solver may run as a stand-alone CFD solver, where only fluid dynamics effects are studied, or it can be coupled to the solid mechanics solver to study loosely or strongly coupled Fluid-Structure Interaction (FSI) problems.

First the classic flow around a cylinder was considered to confirm the solver's ability to correctly reproduce simulated phenomena. The flow around a cylinder has been widely used both as a numerical validation test case as well as a research case [1], [2]. Depending on the Reynolds number [1], [6], [17] the following behaviours of the flow can be identified:

$Re < 50$ – a steady laminar flow with symmetric separation (Figure 2a),
$50 < Re < 160 - 190$ – a Karman Vortex street (Figure 2b),
$190 < Re < 1300$ – laminar with vortex street instabilities,
$190 < Re < 1300$ – a laminar-turbulent transition; a turbulent separation and reattachment, a turbulent wake.

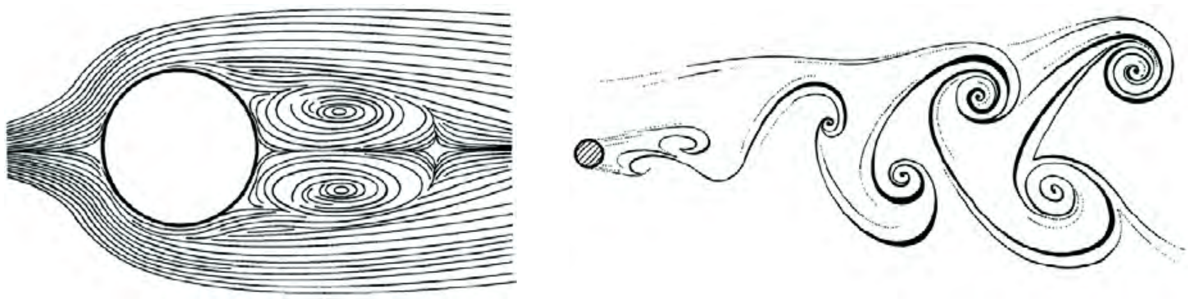
According to the available literature [2], the comparison was focused on the two values of viscosity corresponding to the Reynolds number values of $R_e = 40$ and $R_e = 100$. In the considered case, the values of pressure and lift was compared to those available in the literature and simulation to ensure correctness of the research where regime of the Reynolds number should be in a range 100 to 120.

For the $R_e = 40$ case, the boundary layer separation point of the laminar stationary flow was analyzed as well as the reattachment length. For the $Re = 100$ case, the frequency of the vortex shedding was studied through the Strouhal number defined as:

$$St = \frac{RU}{T} \tag{7}$$

where:

R – is the diameter of cylinder,
U – is the incoming velocity,
T – is the oscillation's period.



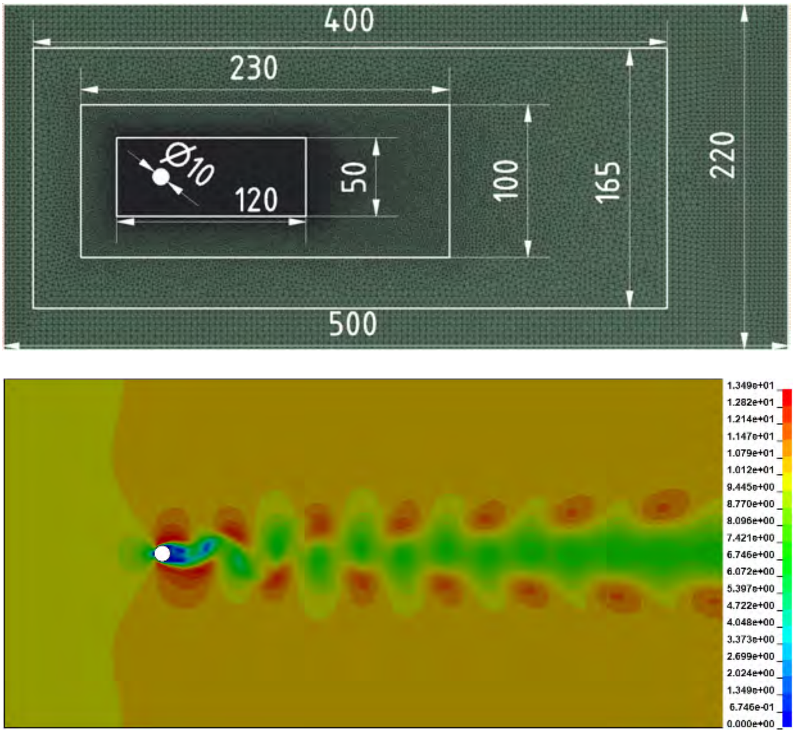
a) b)

Figure 2 Graphical representation of the flow around a cylinder for: a) $R_e = 40$, b) $R_e = 400$

Source: [2]

2.1 Model Description and Simulation Results

The simulation model consists of an inflow with a prescribed velocity, an outflow with a prescribed pressure, two free slip conditions for the remaining boundaries and a non-slip condition on the cylinder. It also contains two meshing boxes which will allow a finer volume meshing around the analyzed object and its immediate wake. A complete description of the model's geometry for the cylinder analysis is depicted in the Figure 3a. The resulting volume mesh after running the test case is shown in the Figure 3b.

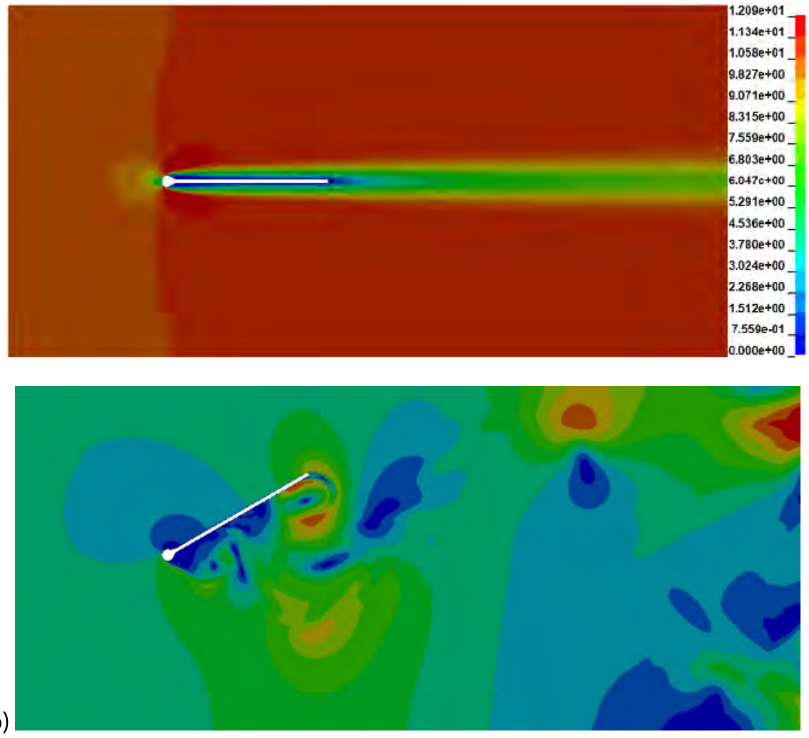


a) b)

Figure 3: a) The graphical example of generated mesh for the flow around a cylinder, b) A fluid velocity for Reynolds number of 100 for a cylinder

Source: own study

The fluid velocity around the fin for a Reynolds number of 100 is presented in the Figure 4a, while the fluid velocity for the fin with the angle of attack α = 30 [deg] is presented in the Figure 4b.



a) b)

Figure 4 A fluid velocity for the fin with an angle of attack: a) $\alpha = 0$ [deg], b) $\alpha = 30$ [deg]

Source: own study

Figure 5 and 6 includes a comparison between the presented analysis and the results achieved from literature [1]. It can be noted that the global behaviour of the presented analysis is in good agreement with the reference results. Starting from the Reynolds number of 40, the error regarding the total drag slowly expands going from 3.8% for $R_e = 40$ to 7.5% for $R_e = 2$ when comparing with the results given by [1]. This can be explained by the fact that, as the Reynolds number decreases and the viscosity increases, the hypothesis used by the Fractional Step method of the solver, (i.e. the diffusion term of the solution due to the viscosity is small compared to the convection term) is slowly reaching its limits. It can also be noted that the error regarding the lift coefficient slowly increases going from 4.1% for $R_e = 80$ to 6.6% for $R_e = 160$. To reduce this error, a finer mesh was used. Finally, for the Reynolds numbers of 4 and 100, some further observations can be made. For the Reynolds number of 40, the boundary layer separation angle occurs at the angle of 54° and the distance between the reattachment point and the cylinder is equal to 2.3 which is in good agreement with the results from literature [1]. For the Reynolds number of 100, the Strouhal number is equal to 0.165 which is in the vicinity of the results given by [1] and [3].

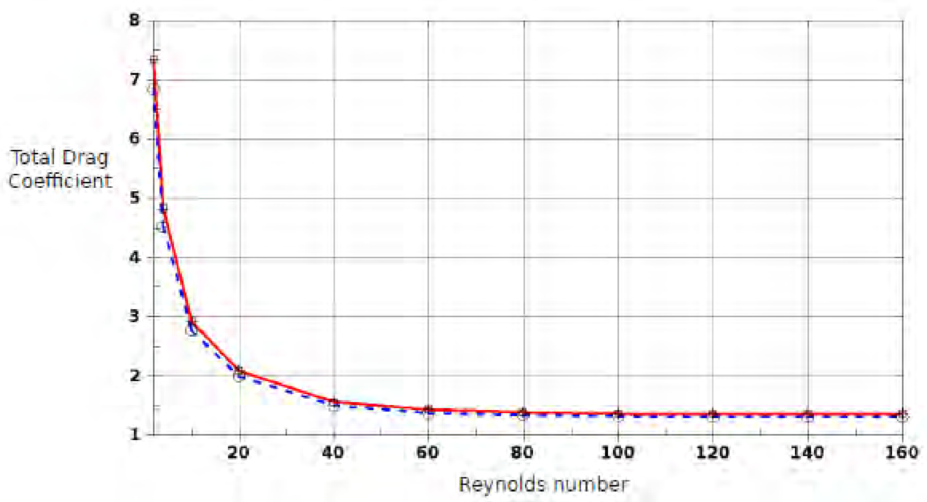


Figure 5 Comparison of the Total Drag Coefficients obtained from the presented analysis (in red) and the results (in blue) given by [1]

Source: own study

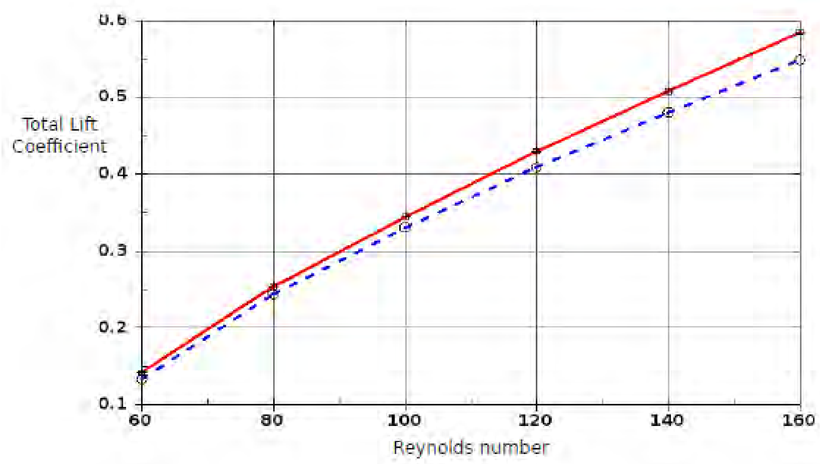


Figure 6 Comparison of the Total Lift Coefficients received from the presented analysis (in red) and the results (in blue) given by [1]

Source: own study

3. THE LABORATORY TEST STAND AND MEASUREMENT METHODS

For the verification of the simulation model the laboratory water tunnel was prepared and equipped with sensors (Figure 7). Two measurement systems were used: the first one for the Fluid Structure Interaction (FSI) force measurement and the second one for the fluid velocity measurement. The different shapes of the fins can be driven by the servo-mechanism (Dynamixel AX-12+) with maximal moment torque 1.5 Nm mounted on the transparent plate. The transparent plate allows to use digital image velocimetry methods. The digital image velocimetry methods were used to determine a laminar and a turbulent areas of the fluid and fluid-structure interaction based on permanent markers with a neutral buoyancy highlighted by the linear laser. In addition, the fluid velocity is measured using the non-invasive method with an ultrasonic flow meter. An external fluid pomp with regulated fluid velocity was implemented into the laboratory test stand.

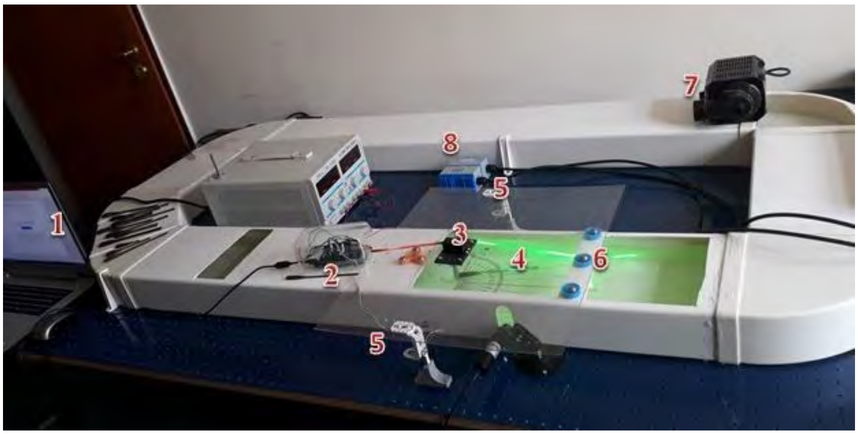
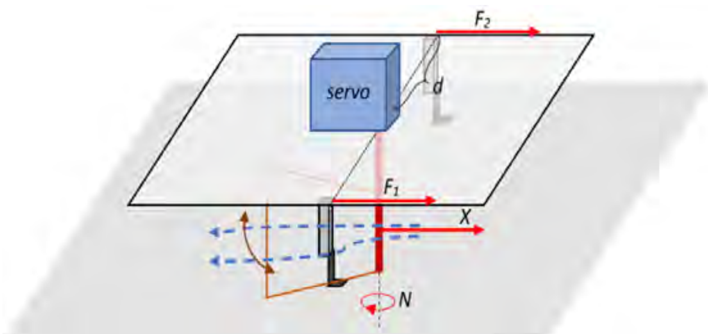


Figure 7 The laboratory water tunnel: 1 – PC, 2 – micro-controller unit, 3 – servomotor, 4 – fin, 5 – strain gauges, 6 – ball bearings, 7 – external water pump, 8 – ultrasonic flow meter

Source: own study

3.1. Force measurement system

The force interaction between the fin and fluid was measured using two precision strain gauges mounted on both sides of the water tunnel (Figure 8). The ball bearings were used for friction reduction and for direct transmission of a force from the fluid-fin interaction into the precise strain gauges system (Figure 7). The scheme of the force measurements is presented in the Figure 8. The analog signals from strain gauges were converted to digital form with 12-bit resolution. For analog to digital converter input equal to 3.3 volt the resolution of the force sensor is equal to $81*10^{-6}$ [N] per one bit. The total range of the measurement force determined by two strain gauge is 0.2 [N].



a)

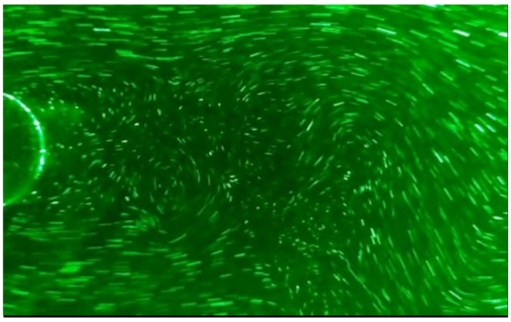
b)

Figure 8 a) Measurement scheme of force X and moment of force N on the basis of forces F_1 and F_2 obtained from the precise strain gauges; b) the photo of strain gauge with Wheatstone bridge for force measurement up to 0.1 [N]

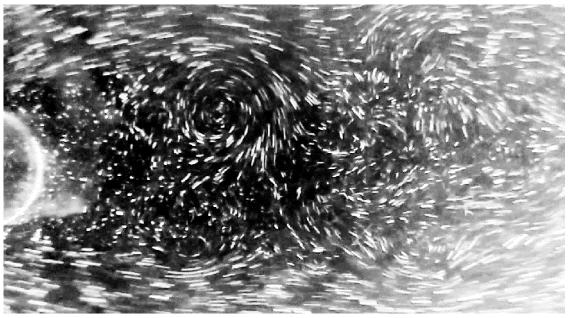
Source: own study

3.2. Particle Image Velocimetry measurement system

The camera with slow motion option was used for tracking the permanent marker (with a neutral buoyancy) highlighted by green linear laser (Figure 9a). Next, the movie was converted to the series of images and the format of each images was changed to the gray one (Figure 9b). To remove uneven illumination issue (such as shadows) the histogram matching algorithm was applied.



a)



b)

Figure 9 The fluid flow behind the cylinder with permanent markers highlighted by the linear laser, a) the picture made during the laboratory tests: b) the picture after conversion to the gray scale and the histogram equalization

Source: own study

For the fluid velocity calculation the normalized cross-correlation method was implemented. The normalized cross-correlation function based on the grayscale images was used to determine the template displacement in each frame from the vision system. The template size was chosen in relation to the fluid velocity, the area of investigation and the camera performance. For the fluid velocity calculation, the algorithms of normalized cross-correlation function were used [7]:

$$\gamma(u,v) = \frac{\sum_{x,y}[f(x,y)-\bar{f}_{u,v}][t(x-u,y-v)-\bar{t}]}{\left\{\sum_{x,y}[f(x,y)-\bar{f}_{u,v}]^2\sum_{x,y}[t(x-u,y-v)-\bar{t}]^2\right\}^{0.5}} \quad (8)$$

where:

f – is the image,
$\bar{t}$ – is the mean of the template,
$\bar{f}_{u,v}$ is the mean of f(*x*,*y*) in the region under template,
u - is the fluid velocity along the measured fluid path,
v - is the fluid velocity perpendicular to the measured fluid path.

For the best correlated images the normalized cross-correlation function achieves the global maximum (Figure 10). Analysis of global and local function (8) maxima allows to check whether the template size is suitable for desired accuracy. The best solution of the velocity calculation is for the one global maximum. In the Figure 10 the example of normalized two-dimensional cross-correlation calculation results is presented for the image with resolution 480x640 pixels.

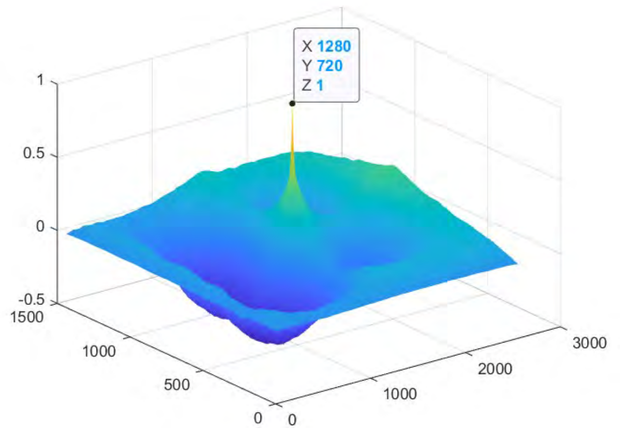


Figure 10 The result of normalized cross-correlation calculation

Source: own study

The fluid velocity was verified in comparison to measurements made by a high-class accuracy ultrasonic flowmeter using the normalized cross-correlation function. For the calibration process the undisturbed flow was taken under consideration. In the next step of research, the normalized cross-correlation function will be used for analyzing the laminar and the turbulent area and their impact on the undulating propulsion system characteristics [10], [23].

4. EXPERIMENTAL VERIFICATION OF THE DRAG FORCE

The drag force was calculated analytically according to the equation (5) and then compared with the results from the simulation and from the measurements (Figure 11). The drag coefficient for cylinder was adopted from literature [17] $C_x = 0.45$. Because the results obtained from the analytic formula, from the simulation model designed in LS-DYNA and from the measurements in the laboratory water tunnel were very similar (Figure 12), it was assumed that the simulation model and the laboratory test stands are ready for the fin analysis. A restriction is only connected with the minimal value of the force that can be measured by strain gauges. It means that the force measurements system is too low for the fluid velocity below 0.1 [m/s].

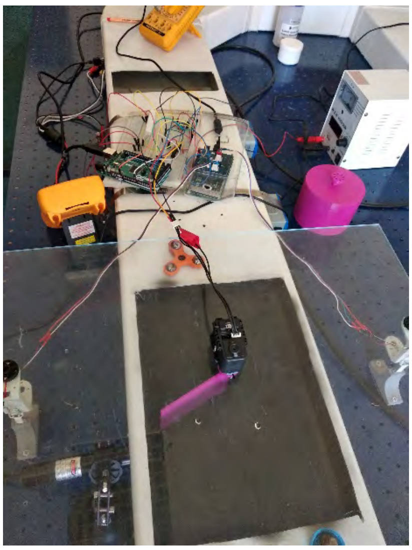


Figure 11 The laboratory test stand with the cylinder and the fin (both are purple) for the drag force measurements

Source: own study

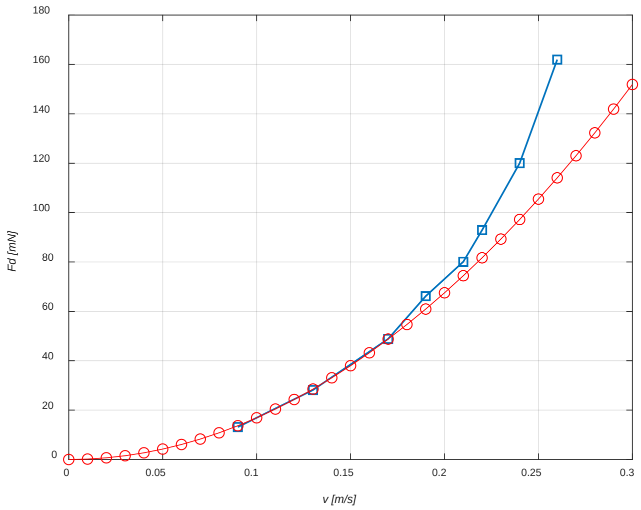


Figure 12 The drag force for the cylinder based on the analytical relations (red colour line with circle makers) and from the measurement experiment (blue line with square markers)

Source: own study

Having done the verification for the cylinder the simulation model was prepared for the fin analysis. In the figures 14-18 the simulation results are depicted for inflexible fin with different angle of attack. In the Figure 13 the results from measurement in the water tunnel are depicted. The maximal velocity achieved from the experiments was dependent on the angle of attack. For the higher angle of attack the fluid velocity was lower. For the $\alpha = 30$ [deg] the maximal fluid velocity $v = 0.3$ [m/s], while for the $\alpha = 90$ [deg] the maximal fluid velocity was equal to $v = 0.21$ [m/s]. For the $\alpha = 0$ [deg] the fluid flow velocity was very similar to the flow without any obstacles, but the strain gauge system was unable to measure the force acting between the fluid and the fin. Due to measuring range of the strain gauges some measurement errors occurred for the fluid flow below 0.1 [m/s]. On the other hand, the differences occurred for the velocity higher than 0.2 [m/s] were caused by the turbulent flow made by narrowing of the water tunnel. That is why the verification of the simulation model for the fin was made for the velocity 0.2 [m/s].

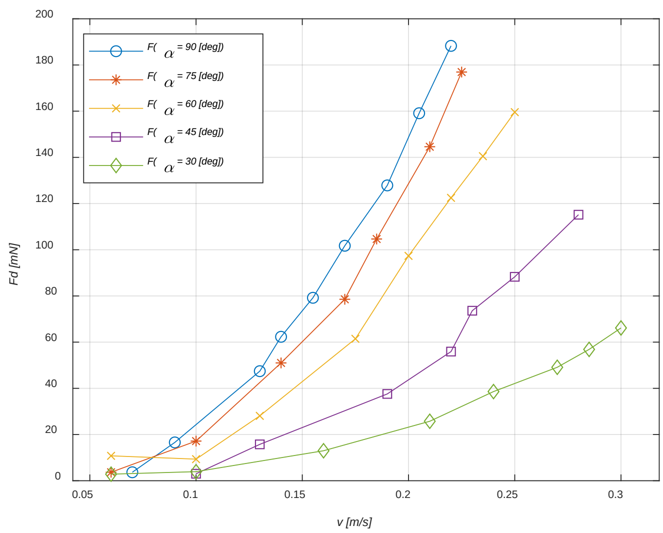


Figure 13 The drag force produced by the fin for different angle of attack (results of measurement in the water tunnel)

Source: own study

In the Figures 14-18 the results of simulations are presented for the inflexible fin with different angle of attack. The fluid flow around the fin is presented and the drag force is depicted below each figure. The simulations were done for constant fluid velocity equal to 0.2 [m/s]. The drag force from simulation model and from experiment in the water tunnel are fit enough for further analysis.

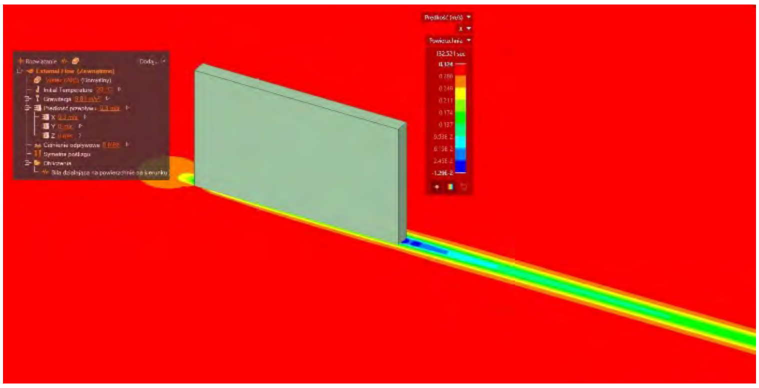


Figure 14 The drag force for the fin with $\alpha = 0$ [deg], $v = 0.2$ [m/s], $F_d = 0.06$ [mN]

Source: own study

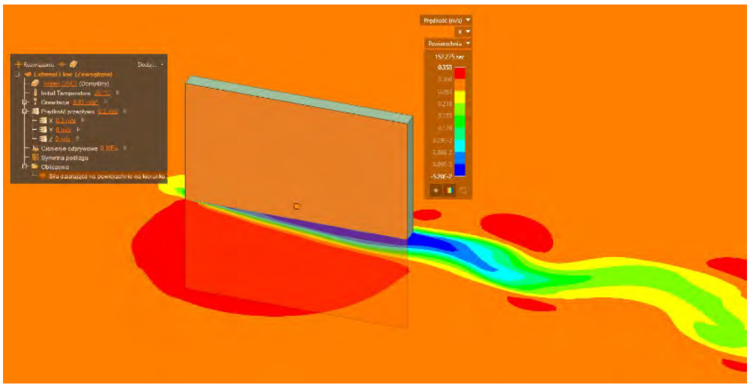


Figure 15 The drag force for the fin with $\alpha = 10$ [deg], $v = 0.2$ [m/s], $F_d = 1.3$ [mN]

Source: own study

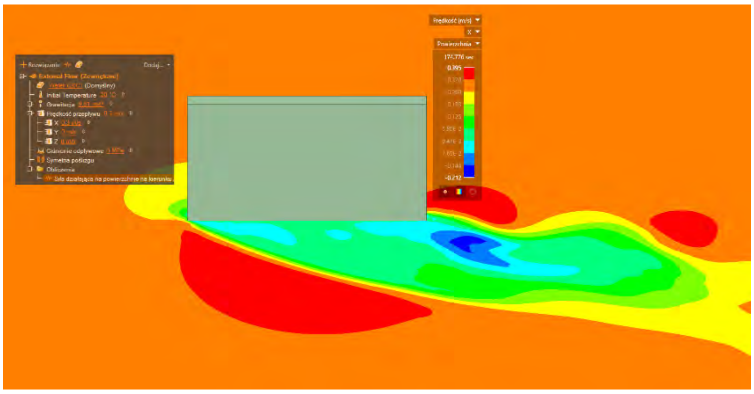


Figure 16 The drag force for the fin with $\alpha = 30$ [deg], $v = 0.2$ [m/s], $F_d = 19.6$ [mN]

Source: own study

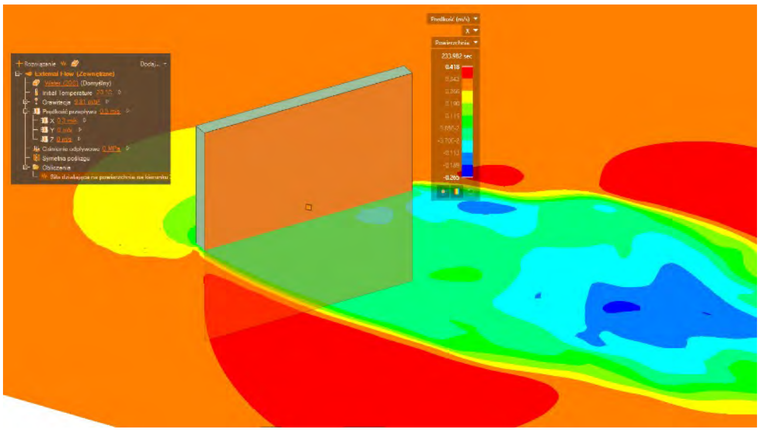


Figure 17 The drag force for the fin with $\alpha = 60$ [deg], $v = 0.2$ [m/s], $F_d = 99.8$ [mN]

Source: own study

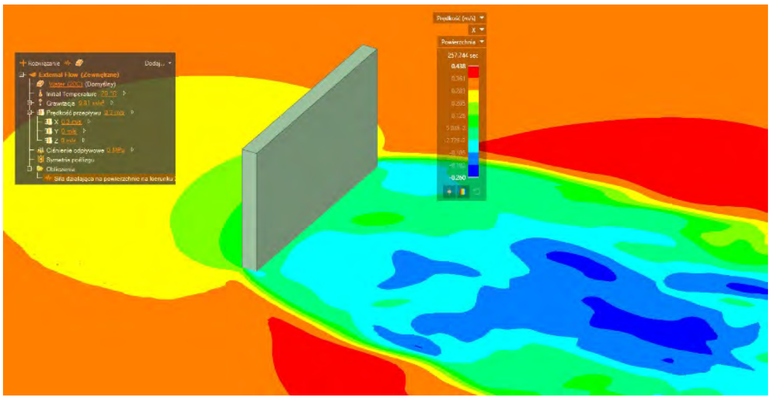


Figure 18 The drag force for the fin with $\alpha = 90$ [deg], $v = 0.2$ [m/s], $F_d = 150.2$ [mN]

Source: own study

5. CONCLUSION

The simulation model made in LS-DYNA package and Incompressible Computational Fluid Dynamics (ICFD) solver was presented. The laboratory water tunnel was depicted focusing on applied measurement methods. The presented vision system will be useful for the impact of design parameters on the analysis of undulating propulsion characteristics. The drag force analysis for the cylinder and the inflexible fin shows that the simulation model can be developed for mechanical aspects for the flexible fin consideration and the propulsion force analysis.

The presented dimensional analysis allows to express all the information contained in the relationships between physical variables of the problem in a very compact form, using a reduced number of dimensionless variables.

Although the simulation method was successfully verified, this is the first stage of the investigation of the fluid structure interaction. In the next step of research, a mechanical solver will be implemented to study material fin flexibility.

The final results of this research will be the set of characteristics with undulating system properties for one-piece flexible fin.

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REFERENCES

[1] An-Qing B., H.-S. D. (2010). Simulation and stability study of the flow around a cylinder in infinite domain, . *Proceding in 7th International Conference on Fluid Mechanics, Qingdao. pp. 68-72*.

[2] Baracu T., G.-B. S. (2014). Computational analysis of the flow around cylinder and of the drag force, . *Proceding in The 2nd Conferece of the Young Researchers from TUCEB (Technical University of Civil Engineering). Bucharest. pp. 16-26*.

[3] Borazjani I., S. F. (2008). Numerical investigation of the hydrodynamics of carangiform swimming in the transitional and inertial flow regimes. *The Journal of Experimental Biology* , p. 1541-1558.

[4] Carey, J. D. (2016). Results from an autonomous underwater vehicle towed hydrophone array experiment in Nantucket Sound.

[5] Connor F. White, Y. L. (2016). Human vs robot: Comparing the viability and utility of autonomus underwater vehicle for the acoustic telemetry tracking of marine organism. *Journal of Experimental Marine Biology and Ecology 485, 112-118*.

[6] GrahamJ., Z. (2000). A numerical study of cylinder sin wave sand currents”. . *Journal of Fluid sand Structures 14.3, p.403–428 doi:10.1006/j#s.1999.0276*.

[7] Haralick, R. M. (1992). Computer and Robot Vision. *Volume II, Addison-Wesley, pp. 316-317.*

[8] J. Wang, X. T. (2014). Averaging of Tail-Actuated Robotic Fish Dynamics through Force and Moment Scaling. *IEEE Transactions on Robotics*.

[9] Koca G.O. Bal C., K. D. (2018). Three-Dimensional Modeling of a Robotic Fish Based on Real Carp Locomotion. *Applied Sciences, doi:10.3390/app8020180*.

[10] Krishnadas A., R. S. (2018). Analysis of biomimetic cadual fin shapes for optimal propulsive efficiency. *Ocean Engineering*.

[11] Lauder, G. V. (2006). Hydrodynamics of undulatory propulsion. *Fish Physiol. 23*, strony 425-468.

[12] Lighthill M.J. (1960). Note on the swimming of slender fish. *Journal of Fluid Mechanics*, strony 305–317.

[13] Liu J., H. H. (2010). Biological Inspiration: From Carangiform Fish to Multi-Joint Robotic Fish . *Journal of Bionic Engineering 7*, strony 35–48 .

[14] Malec M. Morawski M. Szymak P. Trzmiel. (2014). Analysis of Parameters of Traveling Wave Impact on the Speed of Biomimetic Underwater Vehicle. *'Solid State Phenomena'*, strony 273-279.

[15] Morawski M. (2), M. M. (2014). Development of CyberFish – Polish Biomimetic Unmanned Underwater Vehicle BUUV. *Trans Tech Publications, Switzerland*, p. 76-82, doi:10.4028/www.scientific.net/AMM.613.76.

[16] Morawski M., S. A. (2017). Hardware and low-level control of biomimetic underwater vehicle designed to perform ISR tasks. *Journal of Marine Engineering & Technology*, str. http://dx.doi.org/10.1080/20464177.2017.1387089.

[17] Park J., K. K. (1998). Numerical solutions of flow past a circular cylinder at Reynolds numbers up to 160. *KSME international Journal 12.6, p.1200–1205* .

[18] Piskur P. Szymak P. (2017). Algorithms for passive detection of moving vessels in marine environment. *Journal of Marine Engineering & Technology*, p. 377-385.

[19] Szymak P. Morawski M. Malec M. (2012). Conception of Research on Bionic Underwater Vehicle with Undulating Propulsion. *Mechatronics Systems, Mechanics and Materials, Book Series: Solid State Phenomena*, strony 160-166.

[20] Szymak P. Przybylski M. (2018). Thrust Measurement of Biomimetic Underwater Vehicle with Undulating Propulsion. *SCIENTIFIC JOURNAL OF POLISH NAVAL ACADEMY, DOI: 10.2478/sjpna-2018-0014*.

[21] Szymak P., P. T. (2016). *Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR VII,*, str. doi: 10.1117/12.2225587.

[22] Taylor G. K., N. R. (2003). Flying and Swimming Animals At a Strouhal Number Tuned For High Power Eficiency. *Nature*, 707-710.

[23] Wang, C. L. (2017). Optimization of the Kinematic Model for Biomimetic Robotic Fish with Rigid Headshaking Mitigation. *Robotics*, str. doi:10.3390/robotics6040030.

INNOVATION THROUGH COLLABORATION: THE APPLICATION IN MARITIME INDUSTRY

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Summary

The trend of innovation development is becoming increasingly prominent in both, shipping and port business. The most sophisticated ports in the world form clusters and research laboratories where the teams of experts work on the innovations in the area of digitalization and sustainability. The helix models (triple, quadruple and quintuple) were so far investigated in various fields, including maritime sector. This paper examines the application of the helix models in various branches of maritime industry, emphasizes the role of universities in the helix models and explains the concrete examples of maritime clusters as the types of collaboration. The purpose of the paper is to raise the corporate awareness of the importance of the collaboration on the innovations in maritime sector. The paper aims to promote the idea of the innovation development in maritime industry based on the collaboration of different stakeholders (governments, industries, economies, societies and environmentalists).

Keywords: helix model, collaboration, innovation, ports, shipping

1. INTRODUCTION

Maritime business is characterized by dynamic economical, technical and technological, legal, security and safety factors. The previous decades witnessed a change in the business relations between companies as they started to collaborate more on mutual innovation projects. The relevant terms are thus “open innovation” [14] and “innovation through cooperation” [27], which are the consequences of the following circumstances:

(1) Competition became more global and is increasingly driven by innovations, product cycles became shorter, while success is determined by new products and production methods.

(2) Inventions prevalently emerge outside companies. Relations with the inventors outside companies accelerate the progress toward innovation and the market. The inventors take the risk of discovery and initial development.

Within a single company, R&D management can be very complex while the research results are usually poor in comparison with the results that could be obtained through the cooperation with different partners at a global level. This represents an opportunity for companies to adopt and exchange new ideas and to concentrate on (limit) their own restricted resources.

The literature presents a traditional attitude that maritime industry is less open to innovation in comparison with other industries. However, the past decades indicate significant changes in that regard.

Namely, sudden change in the perception of innovations in maritime sector is a consequence of an increased importance of the concept of sustainable development which became one of the most significant competitive priorities in the industry [17]. A space for collaboration and a fruitful ground for innovations came from the adjustment of the world and maritime industry to the dual challenges of an increased sustainability and digital development [17; 3].

Analyzing the competitiveness of maritime clusters, Chul-Hwan (2016) explained the reasons why companies choose open collaboration and join efforts to realize innovations in maritime sector (Figure 1).

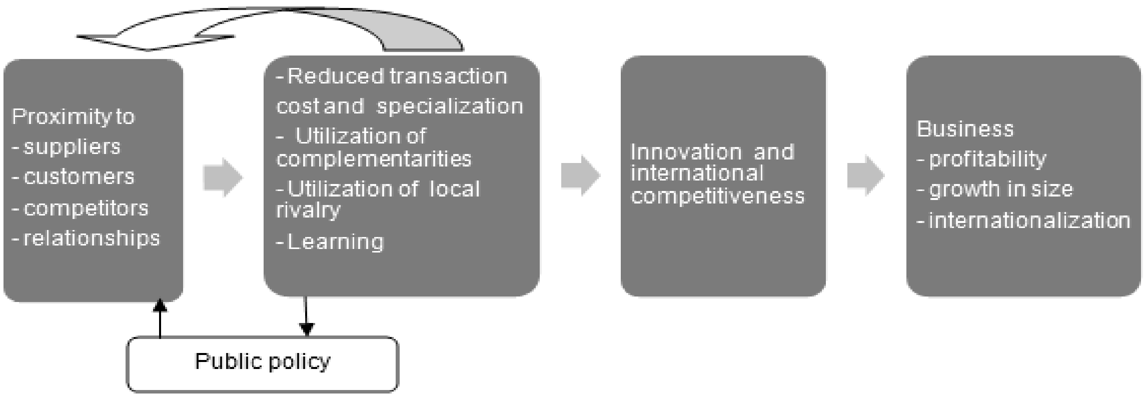

Figure 1. Innovation concept based on cooperation – an example of a cluster

Source: [2, p. 3]

Namely, the vicinity of suppliers, target markets and other segments of business environment lead to the decrease in expenses, the optimization of the production resources (factors), the increase in innovation degrees and, finally, profit, internationalization and the global competitiveness of business [2].

The choice of a proper partner is one of the most important factor for the success of an open innovation. The analysis of a Norwegian maritime company that constructs ecological ships indicates that, under certain circumstances, effectuation is a more suitable approach to open innovations than causation. Innovations are related to the sensitivity of information outflow and therefore, instead of seeking new partners in the open market, the initiators of innovations prefer to collaborate with the existing partners [24].

Jenssen and Randøy (2002) explored the factors that promote the innovation in maritime companies in terms of the following aspects: 1) the innovations of services/products; 2) the market innovations; and 3) the innovations of production methods. The results indicate that an explicit strategy that promotes innovations plays an important role when it comes to the degree of innovations achieved in maritime companies [8].

The examination of Finnish shipbuilding and marine industries confirmed that: a) there are more incremental than radical innovations; b) innovations are more directed toward products, process or service than toward organization and marketing; c) large companies are generally more innovative than micro-companies, d) innovativeness is related to the intensity of in-house and collaborative R&D activities; e) innovativeness differs according to the level of internationalization (exporting companies outperform non-exporting ones in terms of innovativeness) [10].

The cooperation between maritime industry and universities is mainly related to various R&D projects and reports and has an educational character, which multiply benefits the companies – from the development of new products, over competent workforce provision to more abstract contributions such as the comprehension of industrial problems and the industry as a whole [22].

For many maritime companies, the cooperation with partners is an ideal way of developing innovative products and concepts. The symbiotic relations help both partners focus on their own company while relying on the professionalism of a partner company [12].

The twenty-first century innovations in maritime business are implemented through varied projects and mainly refer to the following business aspects: maritime energy efficiency, safety, production, e-maritime, etc [27].

The paper relies on the stance that the business management of innovative activities is a double-edged sword. Namely, innovations may not bring economic success immediately and they always trigger considerable expenses. However, innovations and product development are crucial for maritime industry and will emerge sooner or later thus bringing a competitive advantage to the inventor [10].

The paper further emphasizes the helix models based on multiple collaborations among the partners in maritime industry, examines the role of universities in such collaborations and thoroughly analyzes maritime clusters. Finally, the paper illustrates the concepts mentioned and innovation development through the example of the Port of Rotterdam.

2. THE CONTEMPORARY HELIX MODELS AS A BASIS FOR THE DEVELOPMENT OF MARITIME PARTNERSHIPS

Numerous authors relate innovation management with the development of so-called helix models: triple, quadruple, and the most modern, quintuple helix.

The first model known as the triple helix emerged in the mid-nineties at the time when universities were exhorted by policy makers to collaborate closely in order to contribute to society, which resulted in the commercialization of new knowledge. Innovations happen in the environment of interactions, collaborations and knowledge exchanges among companies, academic institutions and various government agencies. Companies and institutional agents collaborate and participate in networks at various geographical scales – local, regional, national and international [23].

One of the first papers that introduced the concept of the triple helix of the university-industry-government relationships was published by Etzkowitz and Leydesdorff (1995) who interpreted the shift from a dominant, industry-government, dyadic relationship toward the triadic relationship between universities, industry and government in knowledge society [6; 19].

Innovations are highly likely to emerge outside of a single company or even in a different institutional sphere like university, where the focus is on the original pathbreaking developments in both, science and technology. As innovations moved outside of a single organization, cross-boundary lateral relationships became more important than hierarchical bureaucratic structures. An internal transformation of institutional spheres and a new model of the relationships among them was needed for the analysis and future paths of developments [7].

The triple helix is a spiral model of innovation that captures multiple reciprocal relationships at different points in the process of knowledge capitalization. The first dimension of the triple helix model is the internal transformation in each of the helices, such as the development of lateral ties among companies through strategic alliances or an assumption of an economic development mission by universities. The triple helix represents university-industry-government relationships as based on the equality and interdependence between the institutional spheres that overlap and take the roles of each other [7]. Universities transformed from educational institutions into the institutions that combine education and research, since the combination of the two functions is considered more productive and cost-effective [5].

The triple helix model could be defined according to the systems theory as a set of [19]:

a) Components (the institutional spheres of universities, industry and government with a wide range of factors);

b) The relationships between the components (collaboration and conflict moderation, collaborative leadership, substitution and networking);

c) Functions (defined as processes that take place in so-called "Knowledge, Innovation and Consensus Spaces").

This hybrid theoretical approach provides a relevant base for innovation strategies and rectifies some of the key errors in the previous approaches to innovation models such as diffuseness and conceptual heterogeneity, narrow focus on institutions (company-centrism and bias toward R&D intensive and high-tech industries), low visibility of individual innovators and the lack of the identification of system boundaries [19].

The quadruple helix embeds the triple helix and adds the fourth one known as "media and culture based public" and "civil society" [1]. The quintuple helix innovation model is even broader and more comprehensive as it contextualizes the quadruple helix by adding the helix (and perspective) of the "natural environment of society". The triple helix explicitly acknowledges the importance of higher education for innovations. However, a specific interpretation could present the triple helix as compatible with knowledge economy due to the emphasis on knowledge production and innovation in economy. In terms of knowledge production and innovation, the quadruple helix encourages the perspective of knowledge society and knowledge democracy. According to the quadruple helix, the sustainable development of knowledge economy requires a coevolution with knowledge society [1].

The quintuple helix focuses on the necessary socio-ecological transition of society and economy in the twenty-first century which makes this helix ecologically sensitive. Within the framework of the quintuple helix innovation model, the natural environment of society and economy should be understood as a motivation for knowledge production and innovation, which defines the opportunities of knowledge economy. The advocates of the quintuple helix model emphasize the formation of win-win relationships between ecology, knowledge and innovation which would create a synergy between economy, society and democracy. The potential of the quintuple helix could be applied in the areas of ecological importance such as global warming [1].

3. THE APPLICATION OF HELIX MODELS IN THE FIELD OF THE INNOVATIONS IN MARITIME INDUSTRY

Numerous studies on the collaboration between universities, maritime industry and governments aimed to discover the role of each helix in the innovation development process in maritime sector. The previous research mostly linked innovations in maritime industry to clusters and explored the role of companies while the significance of other partners in the development of helix models remained rather implied. In that sense, public sector operations and the companies form other sectors that collaborate with maritime industry remained less investigated [10].

The members of the triple cluster helix gain [11]:

- The access to many marine companies (large companies and small and medium enterprises) and the assistance to convert market opportunity into growth and employment;
- The relationships with scientific base and the understanding of trends and advances;
- The alignment of regional investments in infrastructure, business support and training.

The following section analyzes: a) the role of maritime universities in collaboration with other institutions on innovation development; and b) maritime clusters.

3.1. The Role of Universities in the Innovation Development in Maritime Industry

Interaction is a basis for knowledge transfer, learning, innovation and technology and is, therefore, a basis for the economic prosperity of entire regions, as well. In that sense, the interaction between knowledge producers, disseminators and users is central for sustainable development.

There are several types of collaboration between universities and industry [18]:

- Pure educational collaboration (an example are German and Norwegian universities that generate additional income from tailor-made courses for executives in maritime companies, shipyards and shipping companies);
- R&D collaboration (universities and shipping companies are involved in research projects that are partially funded by the government bodies and partially by companies and universities);
- Commercial collaboration (companies benefit from universities in terms of financial and human resources as well as the provision of simulation services, which are the core competence of universities. Collaborators from shipping companies contribute financial resources).

The turbulent contemporary business environment imposes on maritime companies an obligation to research and engage in innovation development and implementation in order to survive in the demanding environment of growing technology and economy. Governments and maritime companies are willing to support applied research which would result in improved products that would satisfy customer needs better, decrease operational cost and ensure green operations in maritime industry [18].

The main question is how should universities be organized in order to be competitive, attractive partners for collaboration and adjusted to the needs of different maritime markets?

The literature indicates the following findings [18]:

a) Universities should develop competencies in the areas which would be interesting for maritime companies in the near future. It means that there should be a positive relation between the potentials of universities to integrate network resources and to initiate R&D and commercial collaborations.

b) For the purposes of competitiveness, universities should develop an entrepreneurial orientation, which means there should be a positive relation between the orientation and the potential of universities to initiate R&D and commercial collaborations. Likewise, universities could be more proactive in offering their core competences that satisfy the research and development needs of maritime companies. Furthermore, strategic alliances are a way of the unification of the available resources and competences of both, universities and industries, with the aim of the creation of the products for the market. The alliances are currently highly relevant considering that the state budget for academic R&D is constantly reducing.

The collaboration between universities and industries is mutually beneficial. Universities and maritime companies in joint research share physical, human and financial resources. Universities hence benefit in terms of extra income, more time for research and an increased competence of the professors. Maritime companies, on the other hand, gain competitive advantage through innovations. The spin-off from universities is also an important goal of the collaboration between universities and industries [18].

The significance of maritime universities/research centers lies in the provision of the knowledge required for innovations and assistance for naval manufacturers and ship owners in the development of new ship technologies in accordance with environmental standards. Moreover, universities also trigger institutional innovations as they provide organizations and governments with the data for regulation development [15].

The role of universities is nowadays notable when it comes to the realization of the projects on sustainable development and environmental protection. Thus, the collaboration within so-called "green shipping" refers to the following group of related initiatives undertaken in order to encourage the development of environmental management in shipping industry [15]:

- Research and innovation (technological investment) - these initiatives should reduce or alleviate harmful emissions in the environment. The initiatives include the investment into the research and technological design of safer and more sustainable ships.
- Corporate Social Responsibility (CSR) and marketing – these initiatives are incorporated in the European strategy for sustainable and inclusive growth for 2020. The European Commission defines CSR as a concept where companies voluntarily integrate their social and environmental concerns in business operations and interactions with their stakeholders. Shipping operations in accordance with high environmental standards can achieve direct benefits such as company promotion through the improvement of a company's overall image (social responsibility).
- Awareness raising/environmental education – these initiatives are focused on environmental education, awareness raising and the encouragement of the improvements in environmental management across the sector.

Along with the initiatives listed, the triple helix concept is used to establish several frameworks for green shipping. The frameworks refer to the collaboration between three partners: a) Maritime industry (ship owners, naval manufacturers); b) Government regulations (protection, marine ecosystems, regulations); c) Universities / Research centers (IMO, universities, research centers) [9].

An integrated training pathway that defines the roles and responsibilities of both, universities and industries, is a safe model that will create the right kind of workforce for the maritime sector of the future. Universities in Africa, the Baltic region (Latvia and Estonia), Albania, Montenegro, etc. undertook initiatives to adapt the study programs and related curriculums to the needs of the maritime market. Marine engineer, radio, safety and security officers, mates and masters as well as various categories of marine surveyors and staff should be sought under an integrated capacity building program and trained in accordance with the need for the explicit forms of knowledge instead of the tacit ones [16; 22].

3.2. Maritime clusters

In relation to clusters, the literature investigates the following questions [4]:

- What are clusters and what do they consist of?
- How do the partners in a cluster develop collaborative relationships?
- What is the future of maritime clusters and what are the corresponding innovations in ports and shipping?

De Langen and Haezendonck (2012) define cluster as „*a population of geographically concentrated and mutually related business units, associations and public (private) organizations centered around a distinctive economic specialization*". Cluster members are, thus, business units, associations, public-private organizations, and public organizations. Clusters are focused on a particular economic specialization that can be regarded as the core of a cluster. The core should consist of similar and localized activities. Clusters can be local (e.g. a leisure cluster in a city), regional (e.g. a financial cluster in London), or even interregional (e.g. a car manufacturing cluster in South Germany) [4].

The benefits of the companies in clusters are [2, 4, 14]:

- Companies enter clusters because of large labour pools within clusters. The existence of labour pools reduces search cost and provides specific training and education programs which upgrade the quality of labour pools.

- Companies enter clusters because of the suppliers and customers present within clusters. The vicinity of suppliers and customers has financial advantages i.e. reduces transport cost and enables closer monitoring and frequent face-to-face communication.
- Companies enter clusters because of "knowledge spillovers" within clusters. Due to frequent interaction and local development detection, knowledge is easily and more rapidly transferred.

The „agglomeration economies" explain why companies enter clusters [4].

When it comes to the relationships among cluster members, internal competition is seen as an incentive to the improvement of cluster performance because competition fosters specialization and, therefore, from a cluster perspective, enhances the service in specific market segments [4]. Furthermore, the competition in clusters is in many cases "communitarian competition" i.e. constructive competition with a balance between competition and cooperation.

Entry and exit barriers affect the performance of clusters. Entry barriers generally have a detrimental effect on cluster performance, whereas (economic) exit barriers enhance the performance because these barriers firmly tie companies to their cluster.

Heterogeneity of cluster population improves cluster performance, because of the opportunities for the combination of resources, reduction of transaction cost and the range of information spillovers [4].

Leader companies are significant for clusters. The whole cluster benefits from the presence of a leader company because of "multiplier effects" and knowledge spillovers. Leader companies have some of the following characteristics: a) the engagement in structural R&D; b) the access to international markets, and c) the access to international knowledge. The Port of Rotterdam, discussed in chapter 4, is an example of a leader company.

Maritime clusters emerged relatively recently. The majority of maritime clusters was established over the last fifteen years. Salvador (2014) indicates the significance of clusters and underscores that clusters are the only way of escaping obsolescence of maritime sector. He also defines mega-cluster as "*a group of economic sectors that calls upon a set of complementary capabilities and to network associations*" and claims that mega-cluster is the most suitable concept for maritime sector [20].

Maritime clusters can foster innovations only if maritime sector, funding bodies and policy makers take coordinated actions.

All the European maritime clusters could be analyzed with respect to three major areas [21]:

1. *Traditional maritime sectors* (shipping, naval construction, repair and equipment, maritime services, ports, recreational sailing, offshore, navy and inland shipping, etc.);
2. *Tourism and maritime and coastal recreational activities* (cruising and tourism in coastal areas), and
3. *Fishing (fishing, fish processing and aquaculture).*

Similarly, the literature mostly examines following main areas for cluster formation – shipbuilding, shipping, inland shipping, maritime and port services as well as the geographical concentration of maritime activities. Dutch, Norwegian, Swedish, German, Italian and Finnish clusters are the most investigated ones in Europe [2]. Additionally, London Maritime Services Cluster and Hong Kong Maritime Cluster are investigated [2].

Dutch clusters encompass eleven maritime sectors - shipping, shipbuilding, offshore and inland waterways, dredging, ports, navy, fishery, yacht industries and maritime services and suppliers.

The largest port cluster is Rotterdam with over seventy thousand employees. Amsterdam is also a cluster of a substantial size, with forty thousand employees.

Table 1 presents the overview of industries (cargo handling, transport, logistics, manufacturing and trade) and their activities/services that are often involved in port clusters [4].

Table 1. The activities of port clusters

Cluster component	Activities
Cargo handling	Loading, unloading and transshipment activities Pilotage Port engineering
Transport	Shipping services Inland shipping services Salvage services Shipbrokers Rail transport Pipeline transport Trucking services
Logistics	Transport intermediaries (forwarders and ship agents) Warehousing and storage Logistics consultancy services
Manufacturing	Oil refining Flour milling Cokes manufacturing Basic chemical manufacturing Other chemical manufacturing Production of iron and steel Shipbuilding and repair Specialized suppliers to port industries
Trade	Trade intermediaries in oil, fuel and chemical products Trade intermediaries in metals, ores and food Fuel, grain, metals and mineral oil wholesalers

Source: [4, p. 641]

Clusters are a form of collaboration that has recently become a means of adaptation to changes, revitalization and renewal of the varied sectors of maritime economy. For instance, marinas are the main centers of maritime tourism and most of their business is becoming based on the collaboration with other similar marinas, which leads to the formation of clusters [13]. TransEurope Marinas (TEM) is an example of a successful European cross-boundary cluster. The TEM cluster emerged through constant alliances of particular European marinas in the last thirty years. Today, the TEM cluster has the total of eighty-seven marinas in twelve countries and approximately forty-five thousand berths (Figure 2) [25].

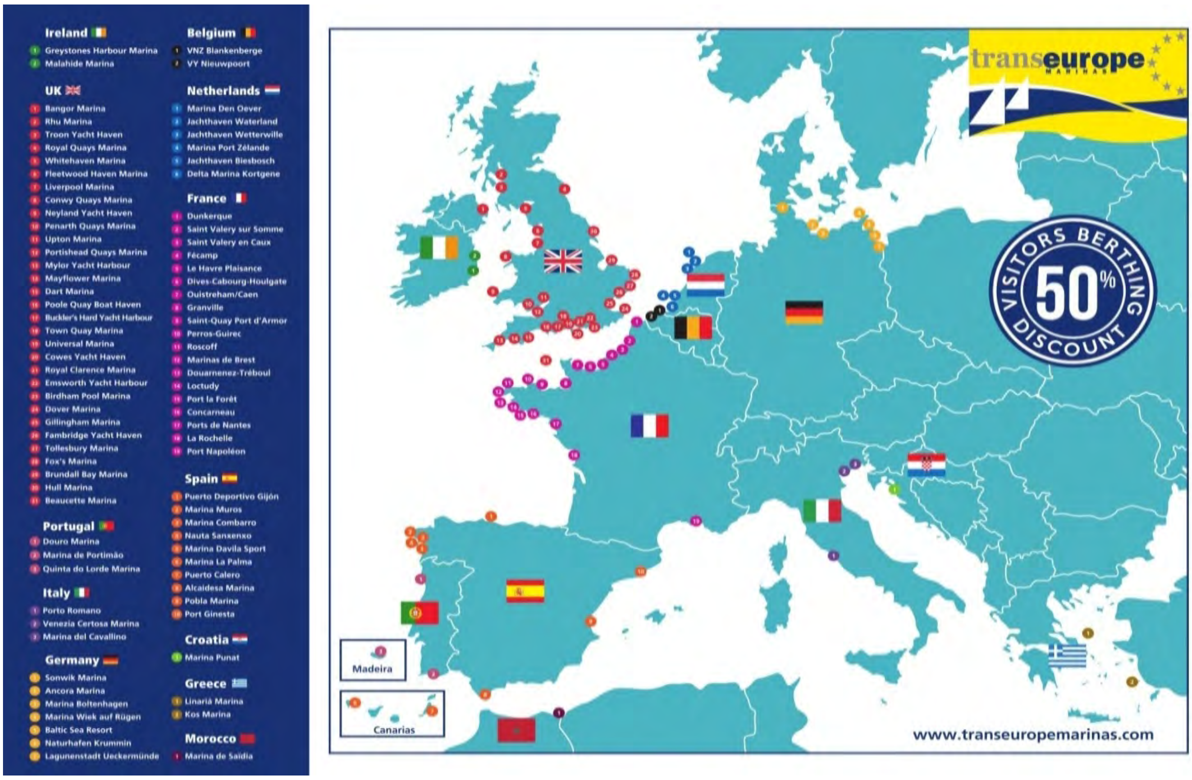

Figure 2 The map of the TEM cluster marinas

Source: [25]

Marina business management within clusters is easier for the cluster members. Marina managers have an opportunity to exchange and expand their knowledge and experience when it comes to competitiveness and recognizability on the market. Likewise, client benefits lie in reciprocal arrangements in marina members that involve the discounts up to 50% [25].

The future development of European maritime clusters (in developing countries) is following [2]:

- Private sector takes initiative for a cluster development and its future progress;
- The Government is necessarily informed about the size, nature and contribution of a cluster to the country;
- Local expertise and knowledge base are established through the strengthening of education and R&D capacities;
- The area of specialization for global and regional leadership is identified because each maritime cluster has unique characteristics due to specific sets of strengths that other overseas competitors cannot replicate;
- Advanced foreign maritime companies should be attracted;
- The strengthening of intra-cluster relationships since they are essential for cluster success ; and
- Public sector should facilitate and regulate the emergence of a cluster and ensure a fair, level playing field within a cluster.

4. THE PRACTICAL EXAMPLES OF INNOVATION THROUGH COLLABORATION IN MARITIME INDUSTRY

The collaboration in the quadruple helix model provides a faster progress for the Port of Rotterdam and Damen company. The teams of experts work on the following innovations [3]:

1. *Pronto - Port Call Optimization*: Many different operations have to be timely performed for each port call. The exchange of planned, expected and realized times facilitates faster finalization of calls and their smarter and more efficient planning. Pronto is an application that shipping companies, agents, terminals and other service providers can use to optimally plan, execute and monitor all activities during port calls based on a standardized data exchange. Over the last year, Pronto was extensively tested during its development phase, so now it can be used by port communities for a fee or data. This tool optimizes port calls by 20%.
2. *Carbon neutrality*: The share of the emissions in the port area is 20% of the total emissions in the Netherlands. The Port of Rotterdam as a leader entered the cluster (so-called "context architect") with the aim of becoming carbon neutral by 2050. Besides the realization that hydrogen is highly important, there were not any specific innovations yet. This realization, however, provides the guidance for the port in terms of the future partnerships and the direction of the investment of the resources that would facilitate further experimentation. For the purposes of experimentation, Damen company, which is a partner in the quintuple helix in the Port of Rotterdam, initiated a project on sustainable vessels such as hybrid tugs, LNG carriers and vessels with LNG propulsion. This kind of innovation should be supported by the government, as well.
3. *A complete digitalization of the port* – The teams of experts are now making the steps toward the production of autonomous vessels while an international standard and the legislation required will be adopted soon. So far, the "Floating Lab" - The Damen Stan Tender - was introduced. Different parties have an opportunity to book the lab and use it for experimentation and learning. Among other aspects, digitalization provides an automatic coupling of towing lines, object recognition and avoidance, etc.

Rotterdam Additive Manufacturing Lab (Ram Lab) exists within the campus for research and development (RDM Campus) in the Port of Rotterdam. The world's first 3D printed class propeller was innovated in Ram Lab. This propeller was tested by Damen company on board Damen Stan Tug 1606.

5. CONCLUSION

The paper aims to promote and describe the business strategy of innovation through collaboration in maritime industry. The review of scientific literature and the application of descriptive method that was based on cabinet research confirmed that maritime industry was not always open to innovation due to the specificities and complexity of the industry as such. However, the development of high technology and the emphasis on sustainable development contributed to the innovative development of maritime sector. An increased need for innovation is proportionate to the increased requirements for efficiency improvement, safety, environmental protection and the digitalization of maritime business.

The complexity of maritime industry lies in numerous activities and stakeholders. Accordingly, adequate partners inside and outside of the industry (governments, universities, R&D centers, specialized organizations) are necessary for a quality collaboration and a successful, mutually beneficial, implementation of innovations. Maritime industry is focused on the improvement and innovation of business operations, while potential partners outside the industry (e.g. governments, universities) focus on local and regional educational development. Such interests are considered synergetic and their proper combination could have multiple effects.

The cotemporary collaboration models (the triple, quadruple and quintuple helix) are all present in maritime business, although the triple and quadruple helices are the most frequently applied. A successful application of these models is best illustrated through the analysis of maritime clusters and then through an example of academic involvement in maritime business projects.

Scientific research proved numerous advantages of collaborative business of any kind. The advantages include increased income, the synergy of knowledge and experience, the reduction of cost and expenses due to the involvement in group schemes, increased competitive advantage, collaborative promotion and branding, improved business profile through the increase in additional value, better approach to new clients and the recognizability on the market.

The paper raises awareness about the significance of collaboration in maritime sector. Collaboration is a way of realizing the necessary innovations in the turbulent business environment of maritime sector. The introduction of innovations generally enhances business operations. Similarly, the paper motivates governments, universities, R&D centers, society and other potential partners to be more open and less sceptic when it comes to the collaboration with maritime industry.

Further research should analyze the formation of maritime clusters in the area of the Adratic Sea.

REFERENCES

[1] Carayannis, G.E., Barth, D.T. and Campbell, F.J.D.: The Quintuple Helix innovation model: global warming as a challenge and driver for innovation, Journal of Innovation and Entrepreneurship A Systems View Across Time and Space, 2012, Vol. 1, No. 2, pp. 1-12, DOI: 10.1186/2192-5372-1-2.

[2] Chul-hwan, H.: Comparative Analysis of World´s Major Maritime Clusters, The Journal of Maritime Business, 2006, No. 81, pp. 89-114.

[3] Damen Magazine: Reijnders, S. and Boer, M.The maritime world of tomorrow, 2018, [cited 2019 January 10], Available at: https://magazine.damen.com/innovation/the-maritime-world-of-tomorrow/.

[4] De Langen, P. W. and Haezendonck, E.: Ports as Clusters of Economic Activity, In book: The Blackwell Companion to Maritime Economics, First Edition. Edited by Wayne K. Talley, Blackwell Publishing Ltd , 2012, pp. 638-654, DOI: 10.1002/9781444345667.ch31.

[5] Etzkowitz H. and Leydesdorff, L.: The dynamics of innovation: from National Systems and ''Mode 2'' to a Triple Helix of university–industry–government relations, Research Policy, 2000, Vol. 29, No. 2, pp. 109–123, DOI: 10.1016/S0048-7333(99)00055-4.

[6] Etzkowitz, H. and Leydesdorff, L.: The Triple Helix: university–industry–government relations: a laboratory forknowledge-based economic development, EASST Review, 1995, Vol. 14, No. 1, pp 14–19. Available at SSRN: https://ssrn.com/abstract=2480085.

[7] Etzkowitz, H.: The Triple Helix of University - Industry – Government Implications for Policy and Evaluation, Working paper 2002·11, Institutet för studier av utbildning och forskning, Stockholm, [cited 2019 January 09]. [cited 2019 January 09]. Available at: http://www.sister.nu/pdf/wp_11.pdf.

[8] Jenssen, J. I. and Randøy,T.: Factors that promote innovation in shipping companies, Maritime Policy & Management, 2002, vol. 29, No. 2, pp.119-133, DOI: 10.1080/03088830110078346.

[9] Lambrou, M., Nikitakos, N., Geragotellis, Y. and Loupassi, C.: Maritime clusters evolution in view with the CoRINThos approach: towards blue economy innovation ecosystems, Econship, 2015, [cited 2019 March 23]. Available at: https://www.researchgate.net/publication/281346060_Maritime_clusters_evolution_in_view_with_the_CoRINThos_approach_towards_blue_economy_innovation_ecosystems.

[10] Makkonen, T., Inkinen, T. and Saarnihttps, J.: Innovation types in the Finnish maritime cluster, WMU Journal of Maritime Affairs, 2013, Vol. 12, No. 1, pp. 1–15.

[11] Marine South East and its partner clusters, E-CASI: European Clusters for Atlantic Strategy Implementation to achieve Socially Inclusive Growth, [cited 2019 January 09]. Available from: https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/docs/body/e-casi_en.pdf.

[12] Maritime Holland, Innovation through cooperation, [cited 2019 January 10]. Available at: https://www.maritimeholland.com/maritime-holland-issue-2/innovation-through-cooperation/.

[13] McKinley, E.: Marina 2020: A Vision for the Future Sustainability of Channel/ Arc Manche Marinas, Industry Report, Recommendations for Best Practice, A Channel Arc Manche Integrated Strategy Project (CAMIS), University of Chichester, 2013, [cited 2019 January 20]. Available at: https://camis.arcmanche.eu/documents/.

[14] Monteiro, P., De Noronha, T.and Neto, P.: A Differentiation Framework for Maritime Clusters: Comparisons across Europe, Sustainability, 2013, Vol. 5, No. 9, pp. 4076-4105, (ISSN 2071-1050) DOI: 10.3390/su5094076.

[15] Nikitakos, N. and Papachristos, D.: Green Shipping Framework Based On the Triple Helix Model, 14th International Conference Research and Development in Mechanical Industry - RaDMI, 2014, 18 -21 September , Topola , Serbia, continued 17 -18 November , Bar and Kotor, Montenegro, pp. 963-971.

[16] Onyemechi, C. and Nwokedi, T.: A Triple Helix Human Development Model for West Africa's Offshore Sector, Journal of Maritime Research, 2014, Vol. 11, No. 3, pp. 79–82, (ISSN: 1697-4040).
[17] Perunović, Z. and Vidić – Perunović, J.: Innovation in the Maritime Industry, POMS 22nd Annual Conference Reno, 2011, April 29 to May 2, Nevada, U.S.A.
[18] Prause, G. and Solesvik, M.: University-Business Cooperation in Maritime Sector–The German-Norwegian Experience, In book: University-Business Cooperation, Publisher: Berliner Wissenschaft Verlag, Editors: G Prause,G. and Venessar, U.,Tallinn, 2011, pp. 20-37.
[19] Ranga, M. and Etzkowitz, H.: Triple Helix Systems: An Analytical Framework for Innovation Policy and Practice in the Knowledge Society, Industry & Higher Education, 2013, Vol. 27, No. 3, pp. 237–262, DOI: 10.5367/ihe.2013.0165.
[20] Salvador, R.: Maritime Clusters Evolution. The (not so) Strange Case of the Portuguese Maritime Cluster, Journal of Maritime Research, 2014, Vol. 11, No. 1, pp. 53–59, (ISSN: 1697-4040).
[21] Scarrott, R.: Roadmap for the implementation of Space-Maritime Cross-sectoral Innovation Networks, with considerations for geographical and sectoral expansion, Technical Report, 2017, DOI: 10.13140/RG.2.2.27298.73927, [cited 2019 August 20]. Available at: https://www.researchgate.net /publication/320907785_Roadmap_for_the_implementation_of_SpaceMaritime_Cross-sectoral_Innovation _Networks_with_considerations_for_geographical_and_sectoral_expansion.
[22] SmartComp Research Report, Maritime companies and their business networks in the Central Baltic region, No. 2, June 2013, [cited 2019 August 23]. Available at: https://www.ubc-sustainable.net/sites/www.ubc-environment.net/files/publications/smartcomp_research_report_2_june_2013.pdf.
[23] Smith, H.L. and Leydesdorff, L.: The Triple Helix in the context of global change: dynamics and challenges, Prometheus, 2014, Vol. 32, No. 4, pp. 321-336, DOI: 10.2139/ssrn.217733.
[24] Solesvik, M.: Open innovation in maritime industry, Shipbuilding and Marine Infrastructure, 2017, No.1, Vol. , pp. 152-157, DOI: 10.15589/SMI20170117.
[25] Transeurope Marinas, Members, 2019, [cited 2019 August 23]. Available at: https://www.transeuropemarinas.com/members/.
[26] Water borne, Maritime innovations for the 21st century - Success stories from EU Research, [cited 2019 Avgust 23]. Available at: https://www.waterborne.eu/media/19995/tra-2016-brochure-final.pdf.
[27] Weiers, G.: Innovation Through Cooperation: The Emergence of an Idea Economy, 2014, Springer (ISSN 2192-8096), DOI 10.1007/978-3-319-00095-4.

A CYBER-SECURITY REVIEW OF EMERGING TECHNOLOGY IN THE MARITIME INDUSTRY

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Summary

The maritime industry is a complex cornerstone of global transportation infrastructure. To ensure smooth, safe and timely operations, technologies have been created or adapted over time to aid the maritime sector. Agile adaptations are an important part of maintaining safe operational standards despite economic, environmental, and technological changes. As ship-based systems and port infrastructure become more technologically advanced and complex, it is important to understand how emerging technology can both improve, and hinder, maritime operations. One of the main drawbacks of evolving technology is the increase of cyber-security vulnerabilities, as these systems become more complex and inter-connected. Maritime technology has the added complexity of hosting both information technology and operational technology (IT and OT) nearly equally. This paper gives an overview of emerging or growing technologies within maritime, specifically how they work, the benefits they bring, as well as cyber-security concerns to consider when accepting them into regular practice.

Keywords: cyber-security, safety, technology, and maritime industry

1. INTRODUCTION

In today's world new, or variants, of existing technology are being integrated into shipping operations to assist in several areas including, but not limited to, logistic services, accurate navigation, frequent communications, and efficient cargo transportation. However as maritime technology becomes more complex and connected, the industry is seeing a rise in cyber-related incidences. Occurrences of cyber incidences, i.e. accidents and intentional attacks, are both fast-rising and significant threats to the industry. In an Allianz risk barometer paper maritime cyber-crime ranked as the second highest-ranked risk in 2018 [1]. This is a significant jump from 2013, when it was not even ranked in top ten risks. It is apparent that, just within the last five years, the vulnerabilities of modern maritime systems and the demands on the industry have increased cyber-risks. The rate of added-complexity, and therefore cyber-risks, is likely to only increase as more technology "emerge" in the maritime industry. This may be the result of new technology or the adaptation of existing technology in a new context.

More specifically, this paper shall look at the cyber-security aspects of autonomy, remote access or control, the Internet-of-Things (IoT), as well as newer renewable energies and cryptography-based security like block-chains. As the global maritime transportation industry moves 90% of all goods [2], any adopted technology will likely be far reaching and experience a wide range of cyber-threats. Cyber-risks arise the larger and more complex code becomes [3], and, due to the size of the industry, maritime organisations face are likely to need complex technical solutions to at both strategic planning and operational levels. The remainder of the paper will be as follows. First, Section 2 introduces cyber-security in maritime, providing some background information. This leads into to Section 3 where a more in-depth discussion of specific technologies that are now being adopted by significant players in the maritime industry and concludes with Section 4.

2. CYBER SECURITY

Maritime transportation, unlike maritime cyber security, has had a long history. Because of this, the industry has faced many threats before, particularly physical attacks like theft. This history means that the industry has built defences and resiliency against these kinds of threats. However, the introduction of electronic systems in a maritime vessel in the early 1900's [4] has changed the potential threats to the industry. Since then, relatively quick integrations of digital systems, both on-shore and on-ship, has helped increase operational efficiency, safety, and reduced physical labour for the crew. Unfortunately, traditional threats like pirates and common criminals have also become more technologically adept, increasing the cyber-threat.

As previously mentioned, a complex computing environment often results in more vulnerabilities in technological systems. More importantly, although individual systems on ships or in ports may not be considered complex by conventional standards, the connected systems (i.e., "system of systems" or SoS [5, 6]) are considerably complex. This is due to the convergence of information technology (IT) and operational technology (OT) that is unique to the modern maritime context. As a transporter of 90% of the world's good in volume and in value [2], many physical operations rely heavily on technology. However, although automation in ports are being developed [7] and there are efforts toward autonomous ships (see more in Section 3.4), humans are still integral to the industry. While OT often receives less cyber-security attention than IT, this is partially because it is less used in other industries, in maritime it is used extensively and should considered a key part of maritime cyber-security. As seen in Figure 1, there are several areas where OT is both required for basic operations, but also integrated with IT systems and human interaction. It is also important to note that, while human error can contribute to physical and cyber incidences [8], a well-trained crew can be an asset in preventing incidences.

There are several reasons why the complexity of systems-of-systems can contribute to cyber-vulnerabilities. Generally when information is in transit, whether wirelessly or through physical wires, there is opportunity to alter or deny data if proper protections and authentications are not in place. In a system-of-system, this problem is compounded as individual systems change, or get replaced, and as they often come from a wide range of manufactures. This is further complicated when considering maritime specifically, given how ships traverse international waters but are still expected to function despite interacting with different regions, technologies, crews, laws and policies. Expecting IT and OT systems to accommodate such a wide set of possibilities can lead to extremely complex systems and create exploitable vulnerabilities.

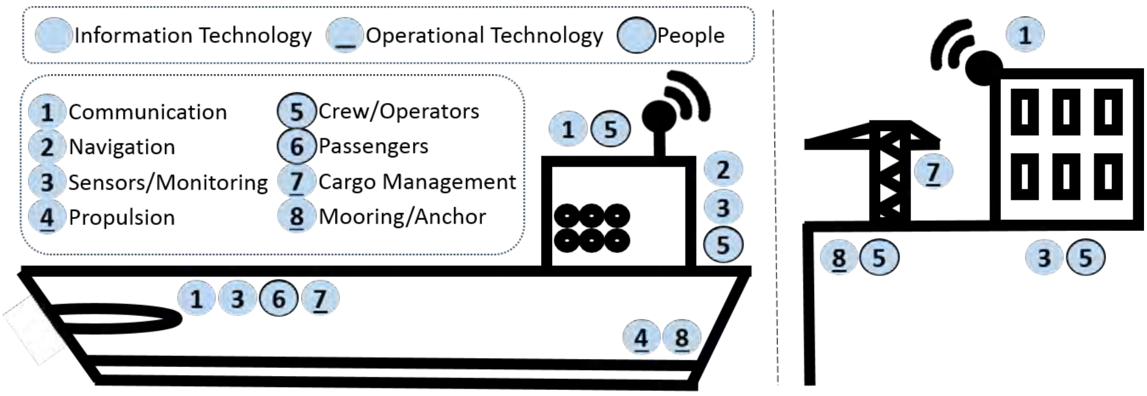

Figure 1 IT, OT, and human elements on-ship and at port

3. EMERGING TECHNOLOGY

This section explores a few technologies that are gaining popularity in the maritime industry with an in-depth cybersecurity perspective. First, Section 3.1-3.4 discusses some maritime relevant cryptography, smart renewable energy, and remote access and remote control technologies. While such topics are less popular compared to the internet of things (IoT) and autonomy, these concepts are central to IoT networks and are found at different levels of autonomy. Lastly, Section 3.5 discusses changes in energy, specifically smart grids and the transition to newer, environmentally friendly, and renewable energies.

3.1. Supply chains: blockchain and "digital twin"

The introduction of blockchains to the computing world has resulted in many innovations and solutions to enhance security. This concept, in essence, decentralizes the storage and access to data. Cryptography is used to create "blocks" of data, and that data's past transactions, and uses secure "chains" to connect those blocks in a fixed order. The cryptographic properties of these blocks and chains allow viewers to see the most current data version as well as the entire transaction history of that piece of data. There has been a lot of excitement surrounding block-chains, however, it is important that the technology is applied correctly in order to solve any existing problems. As highlighted by in-depth studies in [9], blockchains are currently regarded as a new and novel "solutions" to many technical problems; occasionally a technical solution is sometimes picked first, and then applied to a problem without fully understanding whether blockchains are the best solution to that problem. Moreover, in maritime specifically, the benefits are not wholly comprehensive. While the current number of projects involving blockchains in shipping are high, there almost no finished, in-depth projects with meaningful results to assess how well this technology is applicable to the maritime sector [9].

Of the potential applications of blockchain to maritime, the most promising is a secure, distributed, ledger. In this application of blockchain technology, it would become easier to see, and trust the records of, the transactions of goods. Instead of a centralized ledger, a company and the ports it utilizes can distribute a ledger that uses cryptography to ensure that all logs of past transactions are trustworthy, as well as ensure that the information can be public or cryptographically private and secure. The volume of goods in shipping make this a compelling solution in terms of supply chain management [10], general logistics. Cryptographically ensuring trust in ledger entries would add reliability to the system. Moreover, autonomous ports with a de-centralized network would make ledger data more resilient to incidents where one or more locations becomes been compromised.

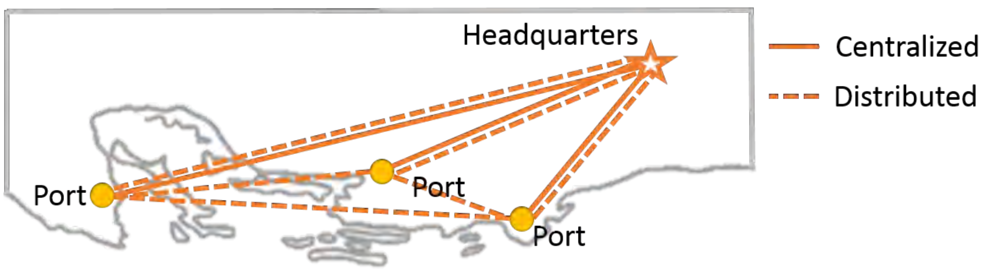

Figure 2 Example of centralized data versus distributed ledges using blockchain technology

Notable efforts by IBM and Maersk are attempting to use global supply blockchains on 10 milling shipping containers [11]. An example of centralized and distributed networks can be seen in Figure 2. As can been seen, the main difference in this simplified example is that the ports are more involved in the data distribution of cargo transactions, storing the ledger, and communications with all parties. While more complex, the actual transactions are also more secure and there is less reliance on a central location to protect a ledger on its own. While blockchain-enabled secure ledgers for the supply chain is an emerging technology to aid the transport of goods, "digital twin" technology is emerging to aid ship design, construction, and track ship performance across its life cycle. Similar to the IBM and Maersk project driving blockchain in shipping logistics, DNV GL, Rolls-Royce and several other groups are driving digital twin projects for ships.

The core of the "digital twin" concept is driven by sophisticated simulations of a physical assets, like a ship, by creating a suite of simulations models that can be placed in a common platform. This platform would allow a number of simulation models to be loaded at one time and to interact with each other, allowing for a highly customizable platform for a multitude of analysis. In terms of cyber-security, the digital twin cannot easily enhance cyber-security analysis capabilities. This is because the components are simulated and would not have the same vulnerabilities as the actual ship. Moreover, while less likely and less effective, since digital twins consist only of virtual parts and reside purely in cyber-space, there is a possibility that the digital files can be targeted in a cyber-attack to affect operations. In summary, while the digital twin might heavily effect the building and monitoring of ships, it is unlikely to have any significant negatives or positives regarding cyber security. Alternatively, there may be several benefits, and not many added vulnerabilities, if the maritime sector accepted secure ledgers. The main concern with applying blockchains to maritime problems is, instead, whether they are best solution. In a white paper by the World Economic Forum [13], a decision tree is available to determine whether a distributed ledger (DLT) is the correct approach for a business. It is advisory for individual businesses to fully consider their problem first before applying DLT. For example, if an asset, or in this case goods, has a physical representation that can change form, it is difficult to effectively manage on a blockchains. In some cases, this could prevent the successful application of a blockchain solution.

3.2. Remote operations and realities

As discussed further in Section 3.4, there are many levels of autonomous and semi-autonomous ships. There are many technologies to aid with middle levels of autonomy, several of which can be considered on their own as significant, emerging, tools for the maritime sector. More specifically this section considers remote communications, remote control, virtual reality, and augmented reality. While there are several communication and networking systems involved in maritime operations (e.g., satellite, radio, internet), the types of cyber-attacks and vulnerabilities are similar due to the wireless transmission. Because of this, no matter how remote access or remote control signals are sent, those transmissions are vulnerable to jamming and potentially spoofing attacks [14]. Based on this analysis of communication technology vulnerabilities in maritime, remote operations where humans receive and send data from on-shore facilities to ships can be vulnerable to cyber-attacks. Because of this, using virtual reality as a remote control aid has similar vulnerabilities. Hence, it is important to make sure all communications are trustworthy and to set up contingencies if communications are untrustworthy or unreliable.

Augmented reality, unlike virtual reality and remote operations, is more helpful to a crew on a manned ship, instead of a remote crew. This means that it does not share the same communication-based cyber-vulnerabilities. However, similar to virtual reality, the dangers lie in misinformation causing people to make the wrong decisions. This is because virtual objects are less easily verifiable, meaning if a cyber-attack is able to alter data, the likelihood that the false information is discovered before an incident goes down. This kind of vulnerability has been speculated about before with eAtons [14] as they are virtual markers and could potentially be spoofed or altered. Considering newer, emerging technology, augmented systems for ship bridges could result in a wider range of incidences, as there are more ways to trick people. The benefits of augmented bridges, disregarding security, is how data can be displayed in a more human-friendly manner [15, 16]. In particular, using augmented systems in areas difficult to navigate, and difficult to place physical markers, can make navigation much easier. Artic waters in particular has highlighted the benefits to eAtons as well as augmented realities on bridges [16]. An example of how malicious changes to the underlying data of an augmented reality program is changing the correct shipping lane on the screen enough to increase the changes of a collision with ice.

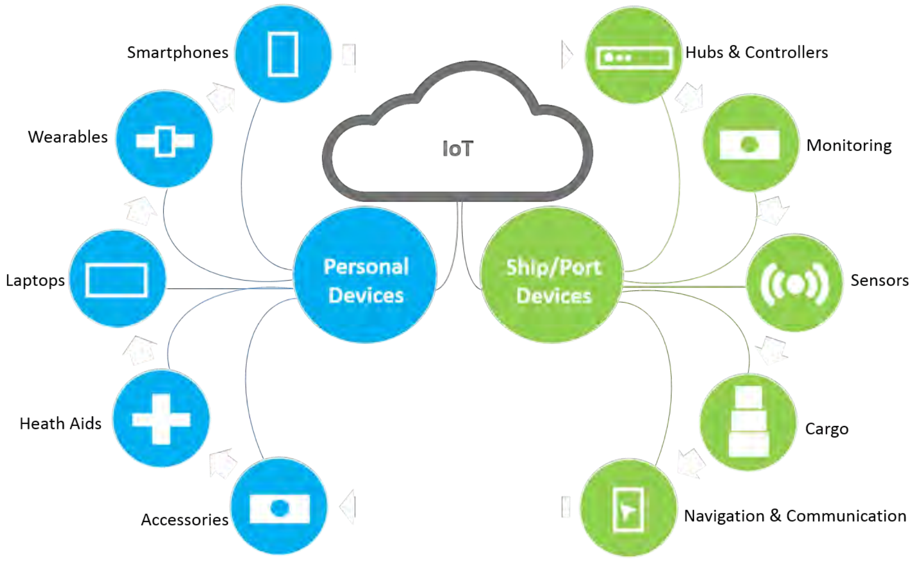

Figure 3 Categories of devices, personal, ship, and port, within a maritime Internet-of-Things

3.3. IoT

The internet of things (IoT) is the concept that many types of devices are interconnected, and share vast amounts of data, via the Internet. As this definition is relatively broad, IoT networks are inherently massive considering the number and types of internet-connected devices in the modern world. More specifically, in a recent survey, maritime trends show that 42% of maritime organisations believe they can benefit from additional IoT skills and 2.5 million dollars will be spent on IoT solutions over the next three years, more than cloud computing or big data analytics [17]. Part of the driving factor toward IoT solutions is that predicted cost savings are up to 14% over the next five years. Regarding the maritime sector, IoT devices can be categorized broadly into personal devices, ship devices, and port devices. As seen in Figure 3, personal devices and ship/port devices are separated as personal device cyber-security takes generic technology and puts them in a maritime setting, while ship and port devices are more bespoke to the maritime sector even though the underlying technology may be more commonplace. For example, while ships and airplanes may use similar navigation technology, the specific application and security risks will differ because of the context in which they were used. Both personal devices and ship devices are often physically mobile and, based on local and international Internet infrastructures, devices will be mobile across several networks and international lines. These device communications across the Internet are a vulnerable aspect of IoT that must be considered. Moreover, a network is often as secure as its most vulnerable device, meaning device access and permissions must be set accordingly. Sensing devices (e.g., temperature, vibration, sound) in the maritime context are also used differently when compared to other. While many sensors are installed in the control areas, many are also placed in engineering. These support a number of systems and human decisions across a ship, as seen in in Figure 1. This diversity is what separates ship and port devices most from more traditional IoT devices, and defines the unique aspects of a maritime IoT.

Many benefits of an IoT comes from large data analytics and the rich flow of information from multiple sources. In particular, cargo management using IoT enabled tags may revolutionise the shipping industry [18]. Not only would this have significant effects on the maritime industry, if fully implemented and considering the volume of cargo shipped around the globe, maritime devices could become the biggest device contribution to the global IoT. It has been reported that a single modern shipping ship can host 5,000 data tags, and 3,000 sensors across the main control system and engine room [17]. These types of IoT devices can be seen on the ship-device part of the IoT diagram in Figure 3. The diversity and number of devices as well as the maritime cyber-security skill levels of crews today have contributed to 87% of mariners to think their IoT security could be improved [17]. This would mean that a significant portion of a global IoT would be dedicated to maritime operations, therefore also having significant effects on the cyber-security of other industries. Another factor that could lead to maritime devices dominating the IoT space would be if more ships decided to follow the remote control, remote access, or autonomous routes, as they are likely to need more sensors (and monitoring) devices, and more communication devices, to compensate for a reduced crew, or no crew at all [21].

3.4. Autonomy

Because of growing demands on maritime-based trade, many organisations in this sector have begun to consider different levels and types of autonomy as a solution. Autonomous ports, where cargo is handled by advanced OT systems [7, 20], have already been implemented in the real world. Because of the complexity in autonomous navigation, autonomous ships are a little further behind in being fully realised [21]. However, despite the complexity in designing a fully-autonomous ship, the potential reductions of annual operation costs (estimated up to 90%) are a key driver for this emerging technology [22]. Besides the technical challenges, international laws and the risk of the unknown have complicated the progress toward fully autonomous. Because of this, some organisations have opted for lesser degrees of autonomy. While there are definitions for autonomous cars, provided by SAE, there are no formal definitions for different levels of ship autonomy. However, an adaption of SAE autonomous car definitions for autonomous ships has been provided in [21] and simplified into Table 1.

Table 1 Modified SAE autonomy definitions for ships and relevant emerging technology

	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
SAE-based Ship Autonomy	No/minimal autonomy. Small crew required for most, if not all, ship operations.	Partial automation with local crew for simple tasks, e.g. advanced auto pilot.	Conditional autonomy, potential interventions by crew	High autonomy, ship is mostly self-running. Local or onshore crew is rarely required.	Complete autonomous operations in all potential settings.
Remote operations	Not required	Not required	Not required, but likely	Required for operations	Not required, but likely
Sensors / IoT	Needed to aid crew decision	Needed to aid crew decision	Needed to aid crew and autonomy decision	Needed to aid remote crew and autonomy decision	Needed for complete autonomous decisions

Remote access and control, as discussed in Section 3.2, plays into the higher levels of autonomy. With roughly 2GB of data stored per day on a modern ship [17], autonomous ships at tiers 3 and 4 are likely to accrue even more data, in order to feed certain control algorithms, and need to send that data frequently to remote crew. While tier 3 autonomous ships have on-ship crew that can analyse data and react, with a reduced crew it is highly likely that a more specialised off-ship crew will be set up to access data remotely. This can result in communication vulnerabilities, where data can be denied or altered. However, as previously discussed with virtual reality and augmented reality, data can also be altered while stored on the ship or at a remote location. In tier 4 autonomous ships, it is highly likely that both remote access and remote control will be implemented since higher levels of autonomy makes it likely that crew will be off-ship. Lastly, tier 5 autonomy means that, potentially, the ship is fully autonomous and self-directing and does not need contact or assistance from remote crew. However, it is highly unlikely that the owner of the ship will not have contingency plans. Therefore, it is highly likely that remote operations are possible, but unlikely to be used for a fully autonomous ship.

As discussed in Section 3.3, the number of devices that maritime could contribute to an IoT network are extensive. The previous statistics on roughly 3,000 sensors in a modern ship [17] is impressive, however, it has been reasoned that an autonomous ship must host significantly more sensors in order to continue normal operations. This is necessary, as there will be little to no crew to monitor surroundings and ship health and all this data must be gathered digitally [21]. Therefore, it is likely that the number of additional IoT sensors needed to gather critical data for decision-making would increase significantly from tier 1 to tier 5 autonomy. By eventually making sensors the only source of information, the security of the individual sensors themselves should be enhanced as well. Moreover, in these cases data integrity becomes imperative, which makes the secure storage and transfer of this data an important cyber-security decision as this technology develops.

3.5. Energy

Besides cost savings and safer operations, another driver for emerging technology in maritime is protecting the environment. Regulations have changed operations, such as max speeds, however it is important to note that the change of energy collection, storage, and use, will likely have effects on cyber-security as well. By potentially drawing from multiple energy sources, such as wind during a voyage, the energy storage and distribution systems must be able to cope with several inputs as well as outputs and be able to control the flows of energy with high precision. Especially on a ship, which can be highly isolated and stricter with energy consumption, a smart grid may be necessary to direct all these flows [23]. With power systems, for IT and OT, becoming interconnected and integrated with multiple sensors and external systems, this opens a completely new range of cyber threats. Similar to data storage and transfer, energy must be stored safely to prevent hazardous outcomes, and the flow of energy must be correct to both ensure optimal operations as well as prevent certain systems from overloading or systems malfunctioning because they are not receiving enough power. As these renewable energies and smart grids continue to emerge into ships, it is important to note the potential cyber risks.

4. CONCLUSION

In conclusion, the maritime sector is accelerating its use of advanced technology in a wide range of maritime operations. These emerging technologies, whether they be brand new or technology adapted to the maritime sector, have many uses for improving efficiency and physical safety, however, they may also increase the number of cyber-vulnerabilities in ports and ships. This article discussed several of these technologies, including blockchains, the "digital twin", remote operations, virtual/augmented reality, IoT, autonomy, and smart renewable energy. As systems become more interconnected and shift more decision making and operations to computers, both in cyber-space and in the physical world, it is important to note the potential cyber-risks as these technologies become more prevalent in the maritime sector in order build in cyber-protections early on. This will help ensure physical and cyber security as ships evolve, as well as protect shipping operations.

REFERENCES

[1] Allianz. (2018). Allianz risk barameter. Allianz Global Corporate and Speciality SE.

[2] International Maritime Organization (IMO), 2012, "IMO's contribution to sustainable maritime development". Available: http://www.imo.org/en/OurWork/TechnicalCooperation/Documents/Brochure/English.pdf.

[3] R. Subramanyam and M. S. Krishnan, "Empirical analysis of CK metrics for object-oriented design complexity: implications for software defects," in IEEE Transactions on Software Engineering, vol. 29, no. 4, pp. 297-310, April 2003.

[4] D 'amico, Angela & Pittenger, Richard. (2009). A Brief History of Active Sonar. Aquatic Mammals. 35. 426-434426. 10.1578/AM.35.4.2009.426.

[5] Ackoff, Russell, (1971). Towards a System of Systems Concepts. Management Science Vol 17, No. 11. https://doi.org/10.1287/mnsc.17.11.661

[6] Mansouri, Mo & Gorod, Alex & H. Wakeman, Thomas & Sauser, Brian. (2009). Maritime Transportation System of Systems management framework: a System of Systems Engineering approach. Int. J. Ocean Systems Management Int. J. Ocean Systems Management. 1. 200-226. 10.1504/IJOSM.2009.030185.

[7] Rebollo, M & Julián, Vicente & Carrascosa, Carlos & Botti, V. (2019). A multi-agent system for the automation of a port container terminal.

[8] A. Rothblum, "Human error and marine safety," International Workshop on Human Factors in Offshore Operations (HFW2002), 2000.

[9] Verhoeven, Peter and Sinn, Florian and Herden, Tino T., "Examples from Blockchain Implementations in Logistics and Supply Chain Management: Exploring the Mindful Use of a New Technology," Logistics vol 2, 2018.

[10] Boschi, Alexandre & Borin, Rogério & Cesar Raimundo, Julio & Batocchio, Antonio. (2018). An exploration of blockchain technology in supply chain management. 27-28.

[11] Allison, Ian. (2017). Maersk and IBM want 10 million shipping containers on the global supply blockchain by year-end. International Business Times. https://www.ibtimes.co.uk/maersk-ibm-aim-get-10-million-shipping-containers-onto-global-supply-blockchain-by-year-end-1609778

[12] Lo, Chris. (2017). Digital twins in shipping: the open-source approach. Ship Technology. https://www.ship-technology.com/features/digital-twins-shipping-open-source-approach/

[13] World Economic Forum (WEF). (April 2018). "Blockchain beyond the Hype: A Practical Framework for Business Leaders". Available: http://www3.weforum.org/docs/48423_Whether_Blockchain_WP.pdf

[14] Tam K, Jones K. MaCRA: A Model-Based Framework for Maritime Cyber-Risk Assessment, Technical Report, WMU Journal of Maritime Affairs, Jan 2019

[15] Baldauf, Michael & Procee, Stephan. (2014). Augmented Reality in Ships Bridge Operation.

[16] Frydenberg, Synne & Nordby, Kjetil & Eikenes, Jon Olav. (2018). Exploring designs of augmented reality systems for ship bridges in arctic waters.

[17] Drew Brandy, SVP Market Strategy, Inmarsat Maritime. "IoT in Maritime – Inmarsat Research Programme". (2018). Digital Ship – CIOLondon Forum

[18] Jia, Xiaolin & Feng, Quanyuan & Fan, Taihua & Lei, Quanshui. (2012). RFID technology and its applications in Internet of Things (IoT). 2012 2nd International Conference on Consumer Electronics, Communications and Networks, CECNet 2012 - Proceedings. 10.1109/CECNet.2012.6201508.

[19] Rolf H. Weber, "Internet of Things – New security and privacy challenges", Computer Law & Security Review, Volume 26, Issue 1, Pages 23-30. 2010

[20] G. Wilshusen, "Maritime critical infrastructure protection: Dhs needs to enhance efforts to address port cybersecurity," GAO-16-116T, 2015.

[21] K. Tam and K. Jones, "Cyber-risk assessment for autonomous ships," IEEE TCS Cyber Security, 2018.

[22] D. MORRIS, "Worlds first autonomous ship to launch in 2018," http://fortune.com/2017/07/22/first-autonomous-ship-yara-birkeland/, 2017.

[23] G. N. Ericsson, "Cyber Security and Power System Communication—Essential Parts of a Smart Grid Infrastructure," in IEEE Transactions on Power Delivery, vol. 25, no. 3, pp. 1501-1507, July 2010

RESEARCHING ADJUSTMENT OF NOZZLES OF TURBOCHARGER TO IMPROVE THE POWER OUTPUT OF MARINE DIESEL GENERATOR ENGINE

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UDK 621.313:629.5

Summary

This paper presents a method to improve the power output of a marine diesel generator engine. Based on the diesel engine theory, the laws of conservation of energy, and the principle of movement of flow through turbocharger nozzle vanes, authors have built a mathematical model of a real turbocharged engine, concentrating on the mathematic model of nozzles. This model is simulated by Matlab/Simulink program, the simulation shows us the relations between the engine and the turbocharger, the turbine and the compressor, and between the nozzles and the turbocharger. The simulation also determines the influence of nozzles on engine power output and brake mean effective pressure. The simulation results show us that at some cases of load condition, adjusting the cross-sectional area nozzle can improve the power output of the engine.

Keywords: diesel generator engine, turbocharger nozzle, power output, brake mean effective pressure.

1. INTRODUCTION

The turbocharger has been developed steadily since the 1940s [8] and achieved great results. Nowadays, many manufacturers and universities are studying advanced performances of the turbocharger besides reducing emissions. Variable area nozzle turbines are applied widely such as in passenger transport, marine, railway, etc. Reality has proved its effectiveness, including transient response, over-boosting prevention and improved low load condition characteristics. At low engine loads the basic principle of most turbine systems is to narrow the inlet area to the rotor blade of the turbine (reduced A/R ratio) such that air velocity is increased. Conversely, the passage inlet area is opened at higher loads.

Marine diesel generator engines usually operate at a constant speed with a wide range of loads. At 75% to 100% load conditions, the amount of gas provided is enough for diesel engines, however, at lower load conditions, the turbocharger speed becomes slow, the pressure ratio of intake air is low, diesel engines usually operate in lack of fresh air condition, called “black smoke situation”. Besides that, for old engines, after a long time of use, due to leakage, incomplete combustion, a larger amount of air needs to be provided, so the turbo needs to spin faster. There are many of solutions which have been executed, and in this paper a method to solve this problem is also presented.

The aim of this paper is to analyse the relationship and interaction among components, including a marine diesel generator engine and its turbocharger, the main model and sub models are built to describe these relations. The purpose of the simulation program to build ourselves a tool for researching, training and improving the engine's working characteristics. The other aim of the research in this paper is to determine the optimal cross-sectional area of the nozzle in the turbine for each load conditions, applying to the repairing operations and improving the power of old engine kinds. The foundation are aerodynamics and thermodynamics mathematical expressions combined with the Matlab/Simulink tool, which describes very clearly the working processes of a sample engine installed on a ship.

There are many researchers that have researched and built models that simulate turbocharged diesel engine**s**. The foundation theories of diesel engine and turbocharger have been studied by J. Heywood [3], which are used in this paper. To research the combustion process, Weibe [4] model are hugely applied. Woschni model [10] has been used to analyze and calculate the heat transfer through the cylinder wall, head and piston crown. Colin R.Ferguson and Allan T. Kirkpatrick in their research [2] have successfully built models of thermodynamic processes for both gas engines and diesel engines. N.Watson and M.S.Janota [8] studied the charging internal combustion engine, established basics of mathematical models of turbocharger. Lars Eriksson and Lars Niesel [1] solved these thermodynamic mathematical expressions in simplified forms applied widely in the area of the internal combustion engine.

2. MATHEMATICAL MODEL

2.1. Turbine model

2.1.1. Turbine mass flow model:

The performance of a turbocharger can be described by mass flow rate $\dot{m}_t$ (kg/min) and pressure ratio π_t (-). For calculation simplicity, mass flow rate is presented in non – dimensional form $\dot{m}_t\sqrt{T/p}$. The mass flow rate is limited at high pressure ratio by the choking line (when the intake flow velocity reaches the velocity of sound).

Turbine mass flow depends on the area that the flow goes through it [1, 7], it can be expressed as equation **Error! Reference source not found.**

$$\dot{m}_t = A_{Tmax}\frac{p_{03}}{\sqrt{R_e T_{03}}}f_{\pi_t}(\pi_t)f(A_T) \tag{1}$$

Where, $\dot{m}_t$ is the mass flow through nozzle (kg/s); R_e is exhaust gas constant (J/kg.K)

A_T is area of the nozzles (m^2), A_{Tmax} is the maximum of A_T (m^2); p_{03} (N/m^2), T_{03} (K) are the pressure and temperature in the exhaust manifold (before turbine); π_t is pressure ratio (-). The sub models $f_{\pi_t}(\pi_t)$, $f(A_T)$ are sub models that modelled in section 2.1.2

2.1.2. Sub Model f(π_t) and f(A_t):

Sub model f(π_t): f(π_t) is the sub model uses to describe the pressure ratio after and before turbine π_t (π_t=p_{04}/p_{03})

Figure 3 presents a sketch of the turbocharger balance. With p_{03} is the pressure in the manifold before the turbine (N/m^2), p_{04} is the pressure after turbine (N/m^2). Because of $p_{04}<p_{03}$, so that $0<\pi_t< 1$. As the pressure ratio π_t decreases, the corrected mass flow increases until the gas reaches the sonic condition and the flow is choked. We can use the sub model π_t to describe it as follows:

$$f(\pi_t) = \sqrt{1-\pi_t^{k_e}} \tag{2}$$

Where k_e is specific heat capacity ratio of exhaust gas ($k_e=c_p/c_v$).

Sub model f(A_T): To describe the behaviour of nozzles, we use the sub model A_{eff} (A_{eff} is the cross section of nozzles)

$$A_{eff} = A_{Tmax}.f(A_T) \tag{3}$$

According to Lars Eriksson et al [7] ,the equation f(A_T) can be described by part of an ellipse:

$$\left[\frac{f(A_T)-c_1}{c_2}\right]^2 + \left[\frac{A_T-c_3}{c_4}\right]^2 = 1 \tag{4}$$

Where c_1, c_2, c_3, c_4 are tuning parameters.

2.1.3. Turbine efficiency model

The expansion process of exhaust gas from state 3 (p_3, T_3) to state 4 (p_4, T_4). According to N.Watson and M.S. Jonata [8] the efficiency of turbine is defined as the ratio of the polytropic enthalpy $\Delta h_{34,tt}$ (from 3t to 4t) to isentropic enthalpy change (from 3t to 4s) $\Delta h_{s,ts}$

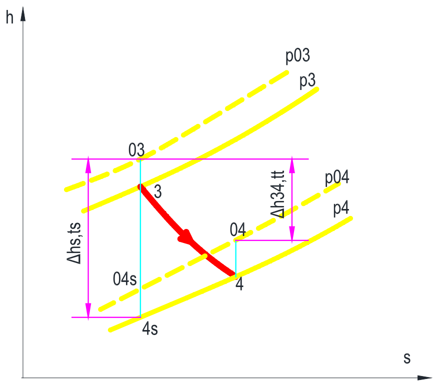

Figure 1 Flow kinetic energy in turbine

The turbine efficiency is defined as

$$\eta_t = \frac{\text{Real turbine work}}{\text{Isentropic turbine work}} = \frac{\Delta h_{34,tt}}{\Delta h_{s,ts}} \tag{5}$$

$$\eta_t = \frac{1-\frac{T_{04}}{T_{03}}}{1-\left(\frac{p_{04}}{p_{03}}\right)^{1-\frac{1}{k_e}}} \tag{6}$$

2.1.4. The effective turbine power model

Due to the expansion of the exhaust gas on turbin blade, the effective turbine power depends on mass flow rate of gas and enthalpy drop in the turbine. It is resulted as [8]

$$\dot{W}_t = \eta_t \dot{m}_t \Delta h_{s,ts} = \eta_t \dot{m}_t c_{pe} T_{03} \left(1 - \left(\frac{p_{04}}{p_{03}} \right)^{1-\frac{1}{k_e}} \right) \tag{7}$$

Where, η_t is the turbine efficiency; $\dot{m}_t$ is the flow rate (kg/s); c_{pe} is the specific heat capacity at constant pressure (J/kg.K); p_{03}, p_{04} are pressure before and after of the turbine (N/m^2), T_{03} is temperature of exhaust gas before the turbine (K); k_e is specific heat capacity ratio of exhaust gas ($k_e=c_p/c_v$)

2.2. Compressor model

2.2.1. Compressor efficiency model

The real compression process in compressor is the polytropic process due to friction and losses in the compressor. The Figure 2 presents the compression process from state 1 at the inlet of compressor (p_1,T_1) to state 2 at the out let of compressor (p_2,T_2). The compressor efficiency is defined as the ratio of the isentropic total enthalpy $\Delta h_{s,tt}$ to the polytropic total enthalpy $\Delta h_{12,tt}$

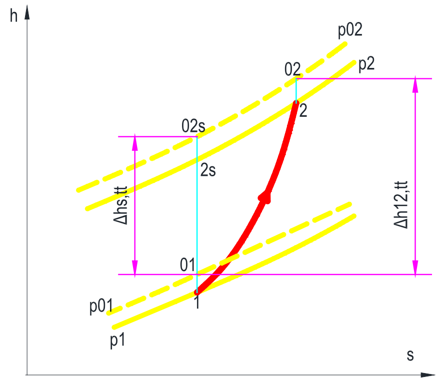

Figure 2 Flow kinetic energy in turbine [5]

The efficiency of compressor presents as below

$$\eta_c = \frac{\text{Power required by an ideal process}}{\text{Power required by an actual process}} \tag{8}$$

$$\eta_c = \frac{\Delta h_{s,tt}}{\Delta h_{12,tt}} = \frac{h_{02s} - h_{01s}}{h_2 - h_1} = \frac{T_{02s} - T_{01}}{T_{02} - T_{01}}$$

The relation among the pressures, temperatures as

$$\frac{p_{02}}{p_{01}} = \left(\frac{T_{02s}}{T_{01}} \right)^{\frac{k_i}{k_i - 1}} \tag{9}$$

Insert **Error! Reference source not found.**) to **Error! Reference source not found.**), the compressor efficiency can be written in term of pressure and temperature as below

$$\eta_c = \frac{\left(\frac{p_{02}}{p_{01}} \right)^{\frac{k_i - 1}{k_i}} - 1}{\left(\frac{T_{02}}{T_{01}} \right) - 1} \tag{10}$$

Where p_{01}, p_{02} are the pressures before and after of compressor (N/m^2), T_{01}, T_{02} are the temperatures air before and after compressor (K); k_i is the specific heat capacity ratio of intake air ($k_i=c_p/c_v$);

2.2.2. Compressor power model

Compressor power can be described by mass flow, temperature, pressure as in [8]

$$\dot{W}_c = \frac{1}{\eta_c}\dot{m}_c c_{pi} T_{01}\left(\left(\frac{p_{02}}{p_{01}}\right)^{1-\frac{1}{k_i}} - 1\right) \tag{11}$$

Where, η_c is the compressor efficiency; $\dot{m}_c$ is the flow rate (kg/s); c_{pi} is the specific heat capacity at constant pressure of intake air (J/kg.K); p_{01}, p_{02} are pressure before and after of compressor (N/m^2), T_{01} is temperature of intake air before the compressor (K); k_i is the specific heat capacity ratio of intake gas ($k_i=c_p/c_v$)

2.3. Turbine and Compressor Balance

The turbine and compressor are mounted on a common shaft (Figure 3). The power of exhaust gas drives compressor blades, the intake air is compressed from temperature T_{01}, pressure p_{01} to temperature T_{02}, pressure p_{02}. The exhaust gas is expanded from temperature T_{03}, pressure p_{03} to temperature T_{04}, pressure p_{04} and release the energy. At steady condition, the power of turbine and the power of compressor are equal (with mechanical loss).

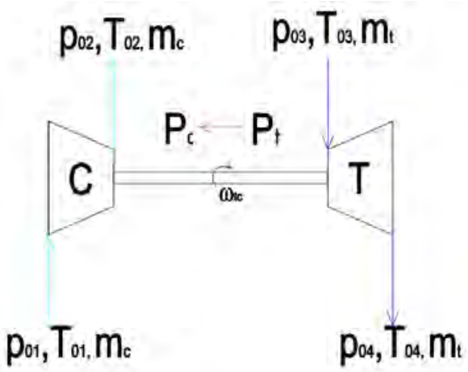

Figure 3. The balance between turbine and compressor

The balance equation of turbin power and compressor power is

$$P_c = \eta_{tm} P_t \tag{12}$$

Where η_{tm} is mechanical loss.

2.4. Temperature and pressure in the intake and exhaust manifolds

Model tempreature and pressure in the intake and exhaust manifolds based on the law of mass conservation, ideal law, gives as

$$\frac{d}{dt}p_{im}=\frac{R_aT_{im}}{V_{im}}\left(\dot{m}_c-\dot{m}_{in\_cyl}\right) \tag{13}$$

$$\frac{d}{dt}p_{em}=\frac{R_eT_{em}}{V_{em}}\left(\dot{m}_{out\_cyl}-\dot{m}_t\right) \tag{14}$$

Where p_{im}, p_{em} are the pressure in the intake and exhaust manifolds (N/m^2); T_{im} ,T_{em} are the temperature in the intake and exhaust manifolds (K); R_a, R_e gas constant of intake and exhaust gases (j/kg.K), V_{im}, V_{em} are the manifold volumes (m^3); $\dot{m}_c$, $\dot{m}_t$ are mass flow through compressor and turbine (kg/s); $\dot{m}_{in\_cyl}$, $\dot{m}_{out\_cyl}$ are the mass flow in and out the cylinders (kg/s), $\dot{m}_{out\_cyl}=\dot{m}_{in\_cyl}+\dot{m}_f$, with $\dot{m}_f$ is fuel mass flow.

2.5. Pressure and temperature in the cylinders

Model pressure and temperature of gas through the cylinder are based on the first law of thermodynamics of the gases inside the combustion chamber, equations of the fuel burning process [4] and the thermo-exchange with the combustion chamber wall [10]

The open system energy equation applied to the cylinder, can be rewrited as:

$$\frac{dp_{cyl}}{d\varphi}=-k_\gamma\frac{p_{cyl}}{V_{cyl}}\frac{dV}{d\varphi}+\frac{(k_\gamma-1)}{V_{cyl}}\left(\frac{dQ_{in}}{d\varphi}-\frac{dQ_{loss}}{d\varphi}\right) \tag{15}$$

$$\frac{dT_{cyl}}{d\varphi}=\frac{dp}{p_{cyl}d\varphi}+\frac{dV}{V_{cyl}d\varphi} \tag{16}$$

Where p_{cyl} (N/m^2), V_{cyl} (m^3) - gas pressure and cylinder volumetric correspond to crank angle φ, $dQ_{in}/d\varphi$ - heat release rate while burning fuel; $dQ_{loss}/d\varphi$ - exchange heat through cylinder wall; $k\gamma = c_p/c_v$ – ratio of specific heats; c_v is the specific heat at constant volume.

Law of fuel burning process.

The increment heat ∂Q_{in} is calculated as:

$$\frac{\partial Q_{in}}{d\varphi}=Q_{in}\frac{dx}{d\varphi} \tag{17}$$

Where, the cumulative burn fraction of fuel (x) is based on double Weibe's formula [4]

$$\frac{dx}{d\varphi}=\frac{dx_1}{d\varphi}+\frac{dx_2}{d\varphi} \tag{18}$$

$$\frac{dx_1}{d\varphi}=\frac{Q_p}{Q_{in}}a(m_p+1)\frac{1}{\varphi_p}\left(\frac{\varphi-\varphi_s}{\varphi_p}\right)^{-a\left(\frac{\varphi-\varphi_s}{\varphi_p}\right)^{m_p+1}} \tag{19}$$

$$\frac{dx_2}{d\varphi}=\frac{Q_d}{Q_{in}}a(m_d+1)\frac{1}{\varphi_d}\left(\frac{\varphi-\varphi_s}{\varphi_d}\right)^{-a\left(\frac{\varphi-\varphi_s}{\varphi_d}\right)^{m_p+1}} \tag{20}$$

Where $dx/d\varphi$ combustion law; $dx_1/d\varphi$ premix combustion law; $dx_2/d\varphi$ diffusion combustion law; a=6.908 Weibe efficiency factor; m_p premix combustion quality factor; m_d diffusion combustion quality factor; φ_s start of combustion; φ_p duration of premix combustion; φ_d duration of diffusion combustion. φ_s is the start of ignition angle of injected fuel, which in turn is affected by the time of ignition delay τ_i (s).

The time of ignition delay τ_i (s) is calculated following Arrhenius model [9]

$$\tau_i = A p_{SOI}^{-n} e^{\frac{T_m}{T_{SOI}}} \tag{21}$$

In which, A and n are experimental coefficients for the specific type of fuel [6]. In this model we used T_m = 2100 ^{0}K, n = 1.02, A = 3.45 and p_{SOI} and T_{SOI} are the pressure and the temperature of the compressed air in cylinder at the start of the injection (SOI) of fuel, respectively.

Heat transfer law. Newton model [2] is used to calculate the heat transfer through surface of the combustion chamber:

$$Q_{loss} = hA(T_{cyl} - T_w) \tag{22}$$

Where, h - heat transfer coefficient (W/m^{2}K), A - exposed combustion chamber surface area (m^2); T - temperature of the cylinder gas (^{0}K); T_w - cylinder wall temperature (^{0}K).

Heat transfer coefficient h is given by Woschni [10]:

$$h = 3.26 p^{0.8} U^{0.8} b^{-0.2} T_{cyl}^{-0.55} \tag{23}$$

Where, p - gas pressure; b - cylinder bore; T_{cyl} - gas temperature; U - gas velocity.

During combustion and expansion, gas velocity is given by:

$$U = 2.28\overline{v}_p + 0.00324 \frac{V_d T_{in}}{p_{in} V_a} p_{cyl} \tag{24}$$

Where, v_p - mean piston velocity (m/s); V_d - displacement volume (m^3); T_{in}(K), p_{in}(N/m^2), V_a (m^3)- gas temperature, gas pressure and cylinder volume at bottom dead center; p_{cyl} – pressure inside cylinder (N/m^2)

Power and efficiency

Indicated Power is defined as the power developed by combustion of fuel inside the engine cylinder.

Brake Power, P_w, is the rate which work is done, therefore, it is the output power. The brake power is less than the indicated power due to frictional loss.

The indicated power determines through its indicated work as

$$W_i = \int p_{cyl}\, dV \tag{25}$$

For diesel engine, indicated power is

$$P_i = i.W_i.n / 2 \tag{26}$$

Where i is the number of cylinders; n is the engine speed (rpm)

The brake power output equation is

$$P_b = P_i - P_f \tag{27}$$

Where P_f is the friction power (loss power). Mean fiction pressure MFP can be modelled according to Eriksson [1]

$$MFP = C_{f0} + C_{f1}\left(\frac{60\,n}{1000}\right) + C_{f2}\left(\frac{60\,n}{1000}\right)^2,\ Pa \tag{28}$$

Where, C_{f0}, C_{f1}, C_{f2} are tuning parameters.

Therefore, the friction power P_f is

$$P_f = i.MFP.V_d.n/2 \tag{29}$$

Where V_d is displacement volume (m^3), n is the engine speed (rpm); i is the number of cylinders

The ratio of the brake power to the indicated power is the mechanical efficiency, η_m

$$\eta_m = \frac{P_b}{Q_{in}} \tag{30}$$

Where Q_{in} is total heat value provided

2.6. Matching turbocharger and diesel generator engine

The Marine diesel generator engine operates by the perfomance of the load, meaning that the engine speed is constant at every load. The engine runs at constant speed, the mass flow rate will increase if load increases, this curve is called engine mass flow characteristic. The air flow through the cylinder may be superimposed on a turbocharger compressor characteristic, as shown in Figure 4. Matching a turbocharger to an engine shows the operational area in which the engine mass flow curve fall through the high efficiency area. The mass flow – pressure characteristic of engine is presented as below

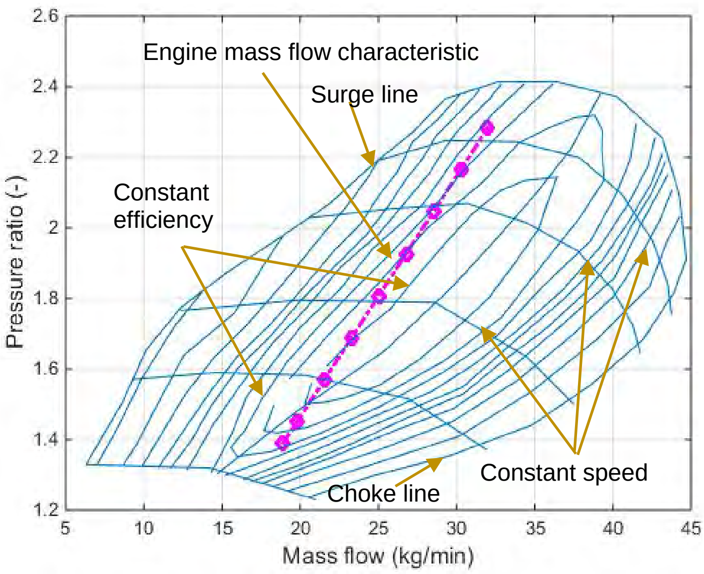

Figure 4 Matching between map compressor and load characteristic

3. SIMULATION RESULTS AND COMMENTS

3.1. Diesel generator engine and simulink model

Diesel engine: The object of research is diesel generator engine Yanmar 6S185L-ST, which is installed on Viet Nam's Cargo Fleets. The main engine parameters are presented as below

Table 1 Engine parameters

DIESEL ENGINE 6S185L-ST	PARAMETERS
Numbers of cylinder	6
Cylinder bore (mm)xstroke(mm)	185x230
Compression ratio	15
Nominal speed (rpm)	900
Brake power (kW)	447
Max combustion pressure (Bar)	13.1
Brake specific fuel consumption, g/kWh	241
Turbocharger VTR160	
Compressor diameter (mm)	171
Compressor A/R	0.6
Turbine diameter (mm)	172
Compressor A/R	0.64

Simulink model:

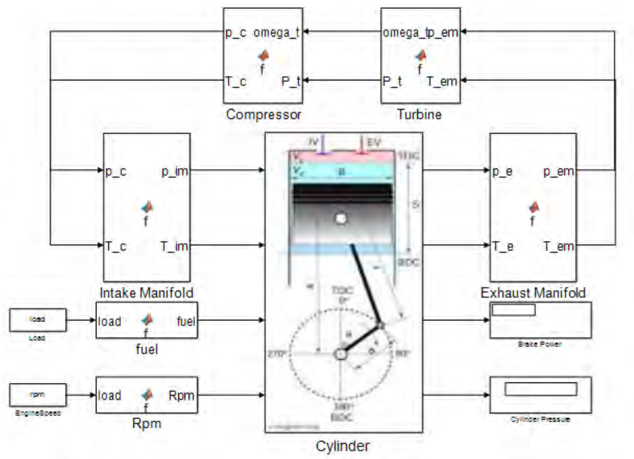

Figure 5 Simulink model of diesel generator engine Yanmar 6S185L-ST

3.2. Simulation results

The simulation at 25% load, 50% load, 75% load and 100% load with differences of nozzle area opening (AT), 100% opening, 80% opening, 60% opening.

3.2.1. Simulation at 25% load

The characteristic of pressure inside cylinder is shown as in the graph below

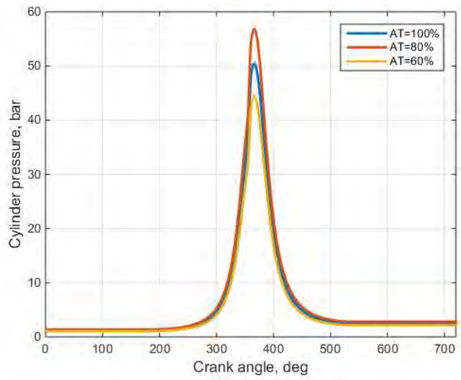

Figure 6 Pressure characteristic at 25% load

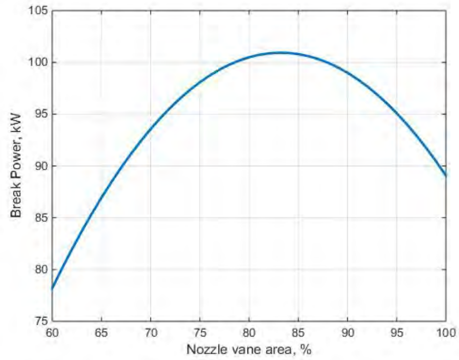

Figure 7 Brake Power varies to the Nozzle area at 25% load

Some of key engine perfomances as Table 2:

Table 2 Brake power output and cylinder pressure following nozzle area adjustment at 25%load

	AT=100%	AT=80%	AT=60%
Max combustion cylinder pressure, bar	50.44	56.81	44.36
Brake mean efficiency pressure (BMEP), bar	4.63	5.22	4.06
Brake Power, kW (increase or decrease)	89.07	105 (+12.8)	78.2 (-12.2%)

At 25% load, the simulation result shows that we can improve cylinder pressure performance by decreasing nozzle area, from 100% to 80%, however if we continue decreasing, the pressure performance goes down and following brake power and efficiency decrease. At the nozzle area AT= 80%, the brake power increases 12.8% but at the nozzle area AT= 60%, it drops by 12.2% (see table 2).

The optimal of nozzle area can be shown as Figure 7, the optimum of nozzle area is 83% of its maximum.

3.2.2. Simulation at 50% load

The characteristic of pressure inside cylinder is shown as in the graph below

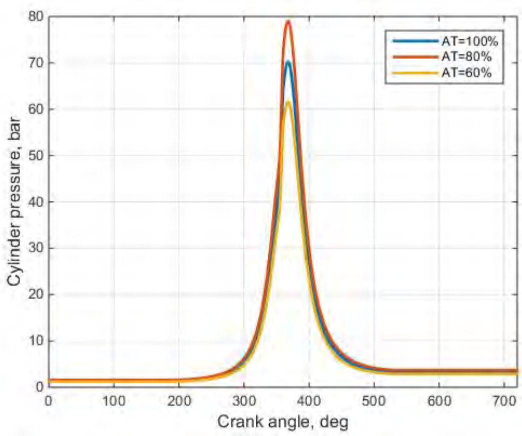

Figure 8 Pressure characteristic at 50% load

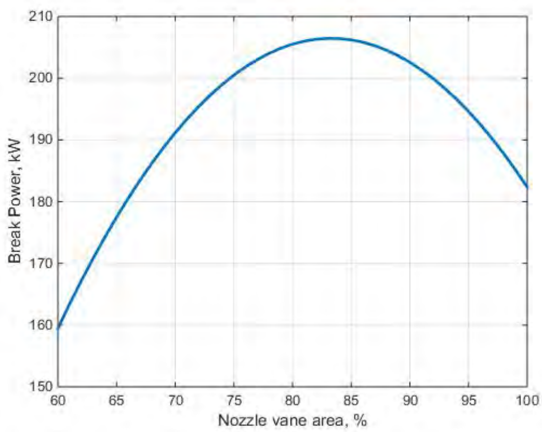

Figure 9 Brake Power varies to the Nozzle area 50% load

At the 50% load regime, to narrow the nozzle area (from AT=100% to AT= 80%), the max combustion pressure and the brake power are increased. After that, they will decrease due to the affection of the back pressure in the manifolds. At the load 50%, the max combustion pressure and brake power increase when the nozzle area reduces from AT=100% to AT=80%, if nozzle area reduces to AT=60% the max combustion pressure and brake power decrease (table 3).

Table 3. Brake power output and cylinder pressure following nozzle area adjustment at 50% load

	AT=100%	AT=80%	AT=60%
Max combustion cylinder pressure, bar	70.24	79.04	61.58
Brake mean efficiency pressure (BMEP), bar	9.47	10.68	8.29
Brake Power, kW (increase or decrease)	182.3	205.5 (+12.71%)	159.4.7 (-12.53%)

The optimal of nozzle area can be shown as in Figure 9, the optimum of nozzle area is 83% of its maximum.

3.2.3. Simulation at 75% load

The characteristic of pressure inside cylinder is shown as in the graph below

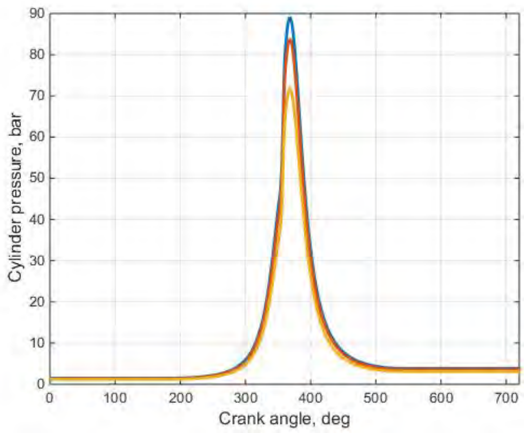

Figure 10 Pressure characteristic at 75% load

Some of key engine perfomances as Table 4:

Table 4 Brake power output and cylinder pressure following nozzle area adjustment at 75%load

	AT=100%	AT=80%	AT=60%
Max combustion cylinder pressure, bar	89	83.7	71.7
Brake mean efficiency pressure (BMEP), bar	14.5	13.6	11.6
Brake Power, kW (increase or decrease)	279.7	262.8 (-6%)	224.6 (19.7%)

At the load 100%, the max pressure decreases rapidly when the nozzle area is reduced (drop from 89.0 bar to 83.7 bar and 71.76 bar while reducing AT=100% to AT=80%, 60%), at the same time, the power reduces 6% and 19.7% respectively.

3.2.4. Simulation at 100% load

The characteristic of pressure inside cylinder is shown as in the graph below

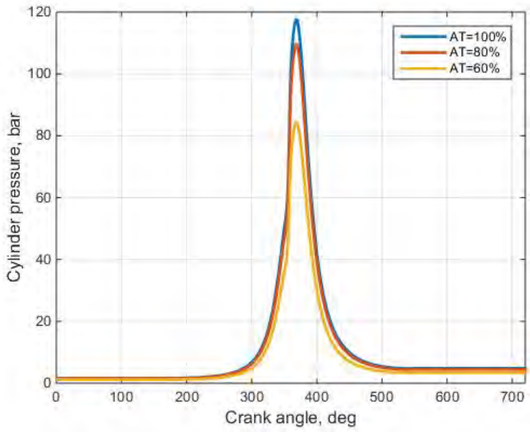

Figure 11 Pressure characteristic at 100% load

Some of key engine perfomances as Table 5:

Table 5 Brake power and cylinder pressure following nozzle area adjustment at 100% load

	AT=100%	AT=80%	AT=60%
Max combustion cylinder pressure, bar	117.6	109.6	84.4
Brake mean efficiency pressure (BMEP), bar	20.6	19.2	14.7
Brake Power, kW (increase or decrease)	396.1	368.8 (-6.9%)	282.4 (-27.7%)

At the load 100%, the max pressure decreases rapidly when the nozzle area is reduced (drops from 117.6 bar to 109.6 bar and 84.4 bar while reducing AT=100% to AT=80%, 60%), at the same time, the power reduces 6.9% and 28.7% respectively. This problem happened because the high pressure and temperature of exhaust gas lead to very high back pressure, poorly affecting the diesel engine's performance. In this situation, the exhaust gas need**s** to be bypassed to reduce turbine speed and reduce pressure of intake air.

4. CONCLUSION

This paper has discussed the diesel generator engine and its turbocharger system, focusing on the turbine's nozzles. Characteristics of gas flows through the engine are studied and modelled by mathematical tools with Matlab/Simulink programming software. A model of the turbocharged diesel generator engine has been completed, which simulated the thermodynamic processes inside the engine and built the relationships between the engine and the turbocharger, the turbine and the compressor, the nozzle and the turbine. The model calculated the engine power output, brake mean efficiency pressure and maximum combustion pressure at the specific regime of load and the nozzle area. The simulation results show that at low loads both engine power and efficiency can be improved by narrowing the turbine nozzle, the cross-sectional area nozzle is 83% its maximum. The minimum area of nozzle is limited by back pressure in exhaust manifold because the back pressure will be high at the high loads and small area of nozzles, therefore amount of the exhaust gas needs to be bypassed. At this situation, we should not narrow the turbine nozzle area. This prediction step could help operators save the maintenance cost and the time of ship operation.

REFERENCES

[1] Eriksson, L. and L. Nielsen, Modeling and control of engines and drivelines. 2014: John Wiley & Sons.

[2] Ferguson, C.R. and A.T. Kirkpatrick, Internal combustion engines: applied thermosciences. 2015: John Wiley & Sons.

[3] Heywood, J.B., Internal combustion engine fundamentals. 1988: New York : McGraw-Hill, [1988] ©1988.

[4] Miyamoto, N., et al., Description and analysis of diesel engine rate of combustion and performance using Wiebe's functions. 1985, SAE Technical Paper.

[5] Nguyen-Schäfer, H., Thermodynamics of Turbochargers, in Rotordynamics of Automotive Turbochargers. 2015, Springer. p. 21-36.

[6] Ramos, J.I., Internal combustion engine modeling. 1989: Hemisphere publishing corporation.

[7] Wahlström, J. and L. Eriksson, Modelling diesel engines with a variable-geometry turbocharger and exhaust gas recirculation by optimization of model parameters for capturing non-linear system dynamics. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 2011. 225(7): p. 960-986.

[8] Watson, N. and M. Janota, Turbocharging the internal combustion engine. London and Basingstoke: THE MACMILLAN PRESS LTD. 1982.

[9] Watson, N., A. Pilley, and M. Marzouk, A combustion correlation for diesel engine simulation. 1980, SAE Technical Paper.

[10] Woschni, G., A universally applicable equation for the instantaneous heat transfer coefficient in the internal combustion engine. 1967, SAE Technical paper.

PROSPECTIVE JOBS FOR MONTENEGRIN SEAFARERS IN THE EPICONTINENTAL AREA OF MONTENEGRO

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Summary

Underwater exploration of oil and gas as a complex technological process is very closely related to shipping, since many processes related to it occur on vessels or depend on them to a large extent. In 2016 and 2017, the Government of Montenegro signed the first concession agreements on exploration and potential exploitation of oil and gas in the exclusive economic zone of Montenegro, thus creating numerous possibilities for employment of Montenegrin seafarers. In order to ensure the competitiveness of our seafarers in this sector, it is imperative to enable our seafarers in Montenegro to obtain additional training with the goal of easier employment in this field. It is also necessary for future concession agreements between the state and oil companies to demand the priority employment of our seafarers in the exclusive economic zone of Montenegro.

Keywords: offshore employment, oil and gas offshore Montenegro, offshore certificates, dynamic positioning certificates

1. INTRODUCTION

The aim of the paper is to point out the possibility of opening new jobs for Montenegrin seafarers within the epicontinental zone of Montenegro, regarding the possible production of hydrocarbons offshore Montenegro. Underwater exploration of oil and gas represents a huge technological challenge and is highly correlated with maritime industry, since these processes largely unfold on vessels or depend upon the very floating structures.

In August 2013, the Ministry of Economy of Montenegro announced the first public call for the concession regarding the exploitation of oil and gas within the 13 blocks of the exclusive economic zone of Montenegro [1]. The total area of the exclusive economic zone is 7,745 km2 and includes the total of 26 blocks (blocks and parts of the blocks) [1]. In September 2016, the first concession agreement was signed with the Eni-Novotek consortium for 4 blocks, and shortly thereafter, in 2017, another agreement was signed with the Greek company Energean for two blocks. In case of oil discovery and commencement of drilling and production process, prospective opportunities for employment of Montenegrin seafarers in this area will be created.

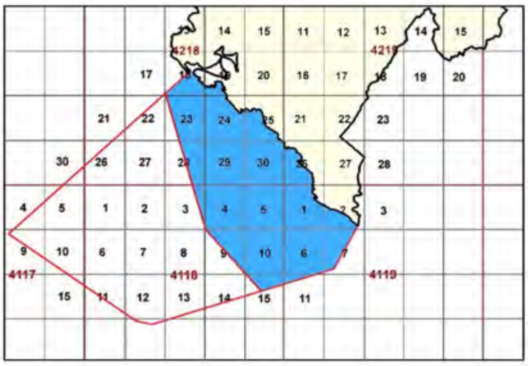

Figure 1 Offshore Montenegro [1]

Nevertheless, the lack of accurate data regarding the number and structure of Montenegrin seafarers is an initial and limiting factor for a deeper analysis of this possibility.

The main goal of this paper is to indicate the positions and installations at which Montenegrin seafarers, who have already been employed by offshore around the world, can be employed in Montenegro, as well as the planned training activities and legal regulations that would help the seafarers employed by merchant fleets to find employment in this sector in Montenegro.

2. BASICS OF OFFSHORE

2.1. Development of an offshore field

The offshore oil and gas production is a much more complex in terms of technology than land drilling, and therefore a much more expensive process.

The technological process related to the exploration and production of oil and gas in offshore can be divided into 5 phases [2]:

- Phase 1, the theoretical assumption of the existence of oil and gas in the target area
- Phase 2, exploration of oil and gas
- Phase 3, the drilling process
- Phase 4, the production process (pumping out oil and gas)
- Phase 5, closing the field and removal of installations

The following graph shows the average duration of the individual phases.

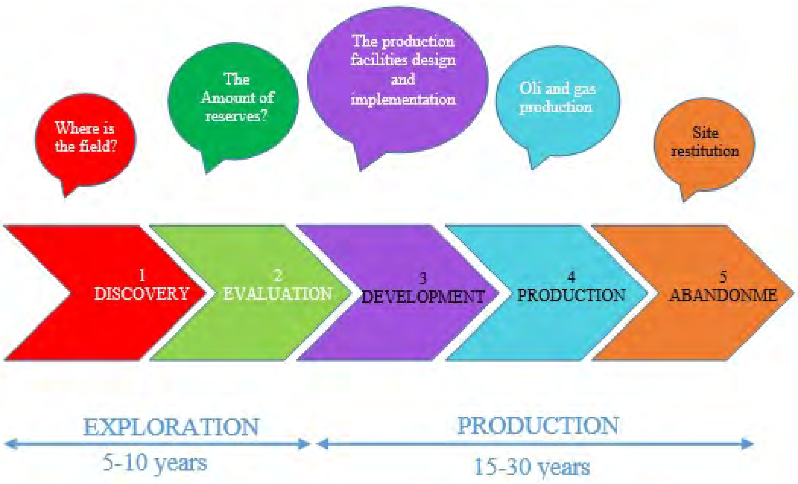

Figure 2 Oil field lifecycle of the oilfield [2]

Considering the creation of new jobs, the most important stage is the production phase during the cycle of which the concessionaire can make the decision to engage domestic workers, or may be obliged by the concession agreement to engage a certain percentage of domestic workers.

2.2. Vessels and the installations on the oil field

The ships and installations used for the purpose are narrowly specialized vessels equipped with specific equipment in order to perform a wide range of offshore operations. In addition to the specialized equipment, a very important element in the operation of these vessels is the crew who, in addition to general maritime skills, possess additional skills that enable them to work on these vessels, such as previously gained experience and specialized training.

Offshore vessels and installations can be classified into several groups:

1. Ships and installations for drilling of oil and gas
2. Offshore service vessels
3. Ships and installations for the production of oil and gas
4. Construction vessels and installations [3].

2.3. Organisational structure of the ships and installations on the oil field

2.3.1. Jack-up and semi-submersible drilling rigs

Except for the geologists and OIM (offshore installation manager), formal education is not a prerequisite for the workforce on a rig. The industrial certifications and work experience represent the best recommendation for getting a job. Specialized training centres provide trainings for drilling safety practices and some other specialized techniques. The only certification that is required for all the personnel is the BOSIET Certificate (Basic Offshore Safety Induction Emergency Training) which comprises first aid, firefighting, helicopter transport and ship to ship transport training [4]. This certificate is not one of the The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) certificates , but without this certificate it is not possible to stay or work on the rig.The number of the crew members will depend on the size of the rig and the equipment used on it, with an average rig having about 50 various employees engaged in the normal working phase. This means that, in order to allow for 24/7 drilling operations in 12-hour shifts, an average crew complement is about 100 persons. What needs to be emphasized is that STCW certificates are not required for jack-up rigs crew, with the exception of the OIM. According to the unwritten rule, initial positions for working on a rig are roustabouts, ordinary workers who may be later on promoted to senior positions.

The typical organizational structure of the crew on a jack-up rig and semi-submersible (semi-sub) rig is shown in the following Figure 3.

Job Classification	On Rig	Total On/Off	Job Description
Offshore Instalation Menager (OIM)	1	2	In charge of all activities and legally responsible for the MODU.
Senior/Day Toolpusher	1	2	In charge of drilling activities and directing personnel that support the "hole making" activities on the MODU
Night Toolpusher	2	2	Similar duties to Day Toolpusher but works at night and usually subordinate to the Day Toolpusher
Driller	2	4	In charge of the drilnoor, drill crews, well progress and reports to the Toolpushers.
Assistant Drillers	2	4	Assists Driller, in charge of drilfloor when Driller not present. Assists Driller in his duties.
Derrickman	2	4	On trips in and out of the well racks pipe in the derrick at the monkey board level and also assists with mud solids equipment and monitoring mud conditions.
Floorman	8	16	Supervised by the Driller and works primarily on the drill floor, substructure and with driling tools
Crane operator	2	4	Operates the rig's cranes and supervises the Roustabout crews.
Roustabout	4	8	Performs manual labor such as painting, unloading boats, carying supplies to store rooms and other manual labor under the direction of the Crane Operalor.
Mechanic	2	4	In charge of all rig mechanical equipment but particularly engines.
Assistant Mechanic	1	2	Splits tours between two hitches of Mechanics. Aids in Mechanic's work and is in training.
Motormen	2	4	Primary duty is to monitor and attend the engine room. Reports to the Mechanic.
Electrician/Electronics Technician	2	4	In charge of all rig electrical and electronic equipment and their maintenance.
Assistant Electrician	1	2	Splits tours between two hitches of Electricians. Aids in Electrician's work and is in training. Reports to lead Electrician.
Welder	1	2	Welds plate and pipe as necessary for driling contracior and operator
Materialsmen	2	4	Handles materials, data entry for maintenance, purchasing, invontory, etc.
Communications Operator	1	2	In charge of communications
Barge Engineer	1	2	In charge of the marine equipment and its operation. In charge during rig moves and jacking. Generaly the maintenance crews and specialists report to the Barge Engineer
Catering/Camp Boss	1	2	In charge of hotol function on rig such as food, laundry. etc
Cooks	2	4	Preperes food.
Galley Hands	10	20	Helps with food, cleans rooms, laundry, etc, under the Camp Boss Totals for basic complement
Total	49	98	Totals for basic complement

1. Crews work 12 hour shifts and usually change at 6:00 AM/PM
2. Individuals with no onboard relief are on call 24 hours per day but usually only work 12 hours per day

Figure 3 Typical MODU crew complement and job responsibilities [5]

2.3.2. Semi-sub DP rig and drill ship

Offshore Installation Manager is on the top of the hierarchy as a captain of this unit because these are self-propelled units. The organisational structure consists of 4 departments [6]:

1. Maintenance department, responsible for maintenance of the equipment.
2. Maritime sector responsible for navigation, ballast, crane and helideck operations.

3. Drilling, responsible for all drilling operations.
4. The administration department responsible for all administrative duties.

As it is the case with jack-up rigs, most of the positions do not require formal education, but experience is the main requirement for employment. In general, STCW certification is not mandatory for all crew members (during the drilling phase) and International maritime organization (IMO) recommendations [7] define the necessary knowledge, experience and STCW certificates for the senior positions only: Offshore Installation Manager, Barge Supervisor, Ballast Control Operator and Maintenance Supervisor.

The navigation officers must also hold the Full DP certificate to operate the DP installation. The Figure 4 shows the typical organizational structure for a drill ship and semi-sub DP rigs.

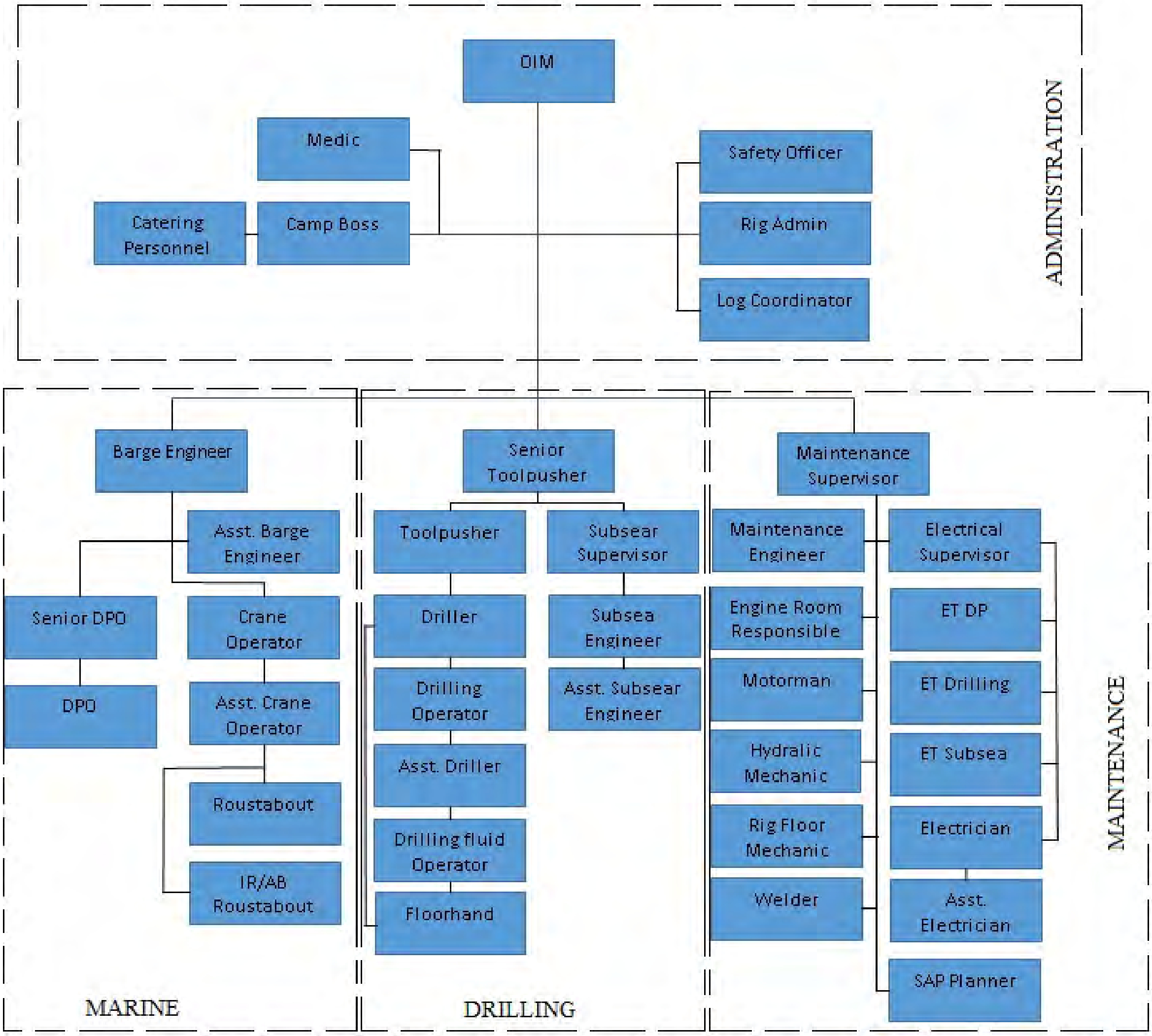

Figure 4 Semi-sub DP rig and drill ship crew [6]

2.3.3. Offshore service vessels

In the offshore oil and gas industry, these types of vessels are used for various purposes (construction, operation, inspection, support, supply and maintenance of offshore installations)[3]. These vessels can be divided into several groups:

1. Seismic survey vessels
2. Platform supply vessels (PSV)
3. Anchor handling ships

4. Crew transfer vessels
5. Construction boats

2.3.4. Seismic survey vessels

These vessels are used only in the initial phase of the potential development of the oil field and only for a few weeks during the seismic survey process. Due to the short period of their presence on the field , we cannot expect the employment of domestic seafarers on these ships during their operation in Montenegrin waters.

2.3.5. Platform supply and anchor handling vessels

The typical organizational structure on these ships shown in Figure 5.

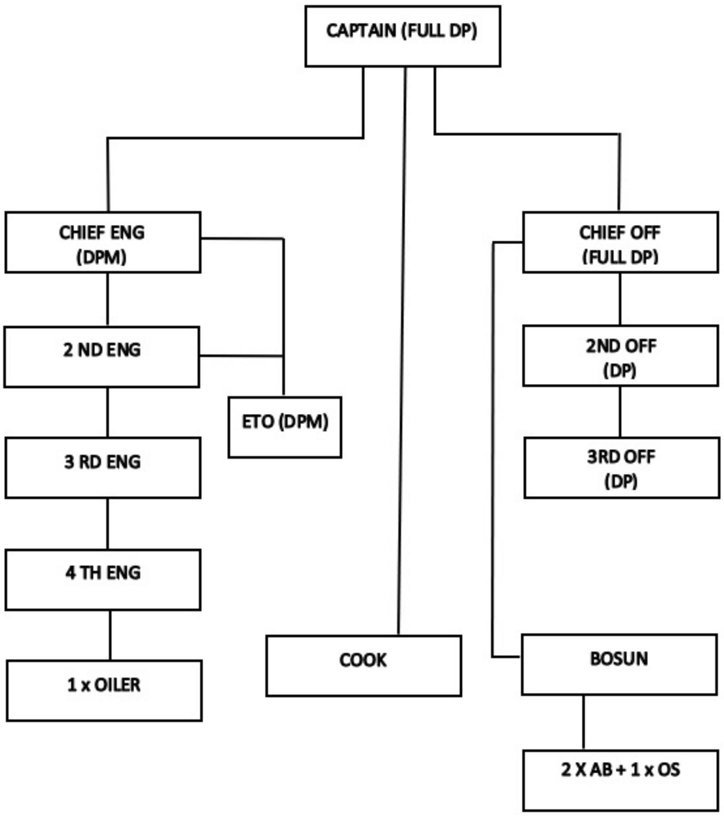

Figure 5 Organizational structure of the vessel (adapted by the author for vessels equipped with a dynamic positioning system)[8]

As it can be seen from the Figure 5, the vessel's organizational structure is more or less the same as on the ships of a merchant fleet. All crew members must possess valid STCW certificates. Considering that these ships are equipped with a dynamic positioning system, the regulations prescribe that navigational officers must also possess valid dynamic positioning certificates (not STCWs) issued by a specialized institution (Nautical Institute) [9].

It is also required that an additional crew member (usually the Chief Engineer or ETO (Electro Technical Officer) must also possess a Dynamic Positioning Maintenance Certificate (DPM) issued by an authorized training centre [9]. For employment on this type of vessels, apart from STCW certificates, it is necessary to have previous supply work experience from supply ships and anchor handling experience from anchor handling ships in the rank in the duration of 1 to 2 years for senior positions (Captain, Chief Officer, Chief Engineer, 2nd Engineer), while junior positions require some offshore experience from some type of offshore vessels [10]. These ships will be present on the oil field from the time the drilling of oil starts until the closure of the oil field, and in case commercial oil reserves are found, these ships might provide additional jobs for seafarers from Montenegro.

2.3.6. Crew transfer vessels

Working on these vessels require relevant STCW certificates. These ships will be present on the oil field throughout all the phases of its life cycle and may provide opportunities for new vacancies.

2.3.7. Construction vessels

This group of vessels represents a wide range of vessels and their organizational structure will not be explained by this paper in more detail due to their great diversity and scope.

2.3.8. Vessels and installations for the production of oil and gas

As with the other installations, the top of the hierarchy is occupied by the OIM as the captain of the installation. The organization structure can be divided into 5 different groups [11]:

1. The production group, responsible for crude oil refining processes.
2. The engine room crew, responsible for the engine room operation and maintenance.
3. Marine group, responsible for navigation, deck, crane and cargo operations.
4. Catering group, responsible for supplies.
5. Safety Officer and Medical Doctor as a separate group responsible for the safety and medical assistance.

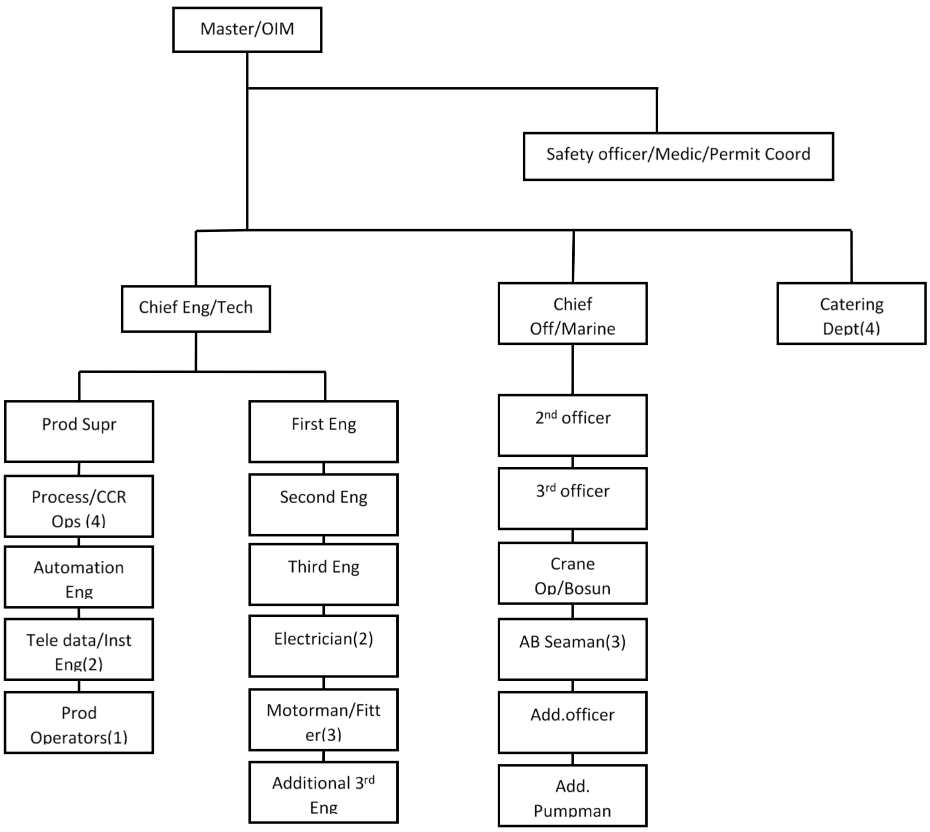

Figure 6 Organizational structure of a floating production storage and offloading (FPSO) installation [11]

FPSO is essentially a floating facility, a converted tanker ship with added oil separation equipment, but IMO defines that, when FPSO is connected via the turret system to the seabed, the STCW Convention does not apply to it (circular [12]).

Due to this regulation, workers with experience and specialized training are given the priority for employment on these installations. As with the other installations, STCW certification is not required. IMO prescribes the possession of valid STCW certificates and specific training only for four key positions, as it is the case with the drill ship [7].

3. OFFSHORE CERTIFICATES

IMO passed the recommendations for the necessary safety training on mobile offshore installations (Recommendation on training of personal mobile offshore units as results of IMO Assembly resolution A.1079 (28)) and it anticipates four categories of personnel on board:

- Category A: Visitors and special personnel not regularly assigned; they usually stay on board for less than 3 days;
- Category B: Other special personnel without designated safety duties;
- Category C: Regularly assigned specialized personnel with designated safety and security duties of others
- Category D: Marine crew members

	Vessel induction	Basic safety training	Specific training in the training and survival of others
Category A[1]	Yes	As appropriate[3]	
Category B[2]	Yes	As appropriate[3]	
Category C	Yes	Yes	As appropriate[4]
Category D	Yes	Yes	As appropriate[5]

Figure 7 IMO recommendations for necessary training (A1079 (28)) [7]

The table (figure 7) further describes that maritime personnel and regular special personnel must possess the Basic Safety Training Certificate issued by a certified training centre and the certificate itself is known as the BOSIET certificate, it doesn't belong to the group of STCW certificate. Currently, in the former Yugoslavia, there is no any certified training centre that can issue the BOSIET certificate as a basic precondition for work on offshore installations.

3.1. Required certificates for key positions on offshore installations

IMO in its resolution A.1079 (28) of 2013 [7] gives recommendations for the necessary level of qualification and specialized training only for key positions on offshore installations.

Key IMO positions on offshore installations are:

- *OIM (Offshore installation manager)*
- *BS (Barge supervisor)*
- *BCO (Ballast control operator)*
- *MS (maintenance supervisor)*

For each of the above key positions mentioned above, the resolution provides a specification of minimum requirements defined by: competences, knowledge, understanding and proficiency, method for demonstrating competences, criteria for evaluating competences [7].

For the above-mentioned positions as per IMO recommendation, extra requirements regarding the required STCW competencies and additional offshore training are required [7].

3.2. Certificates required for officers employed on dynamic positioned vessels

For navigational officers employed on DP vessels, in addition to standard STCW certificates, additional DP certificates are also required. The certification process itself is quite complex and requires a combination of acquiring knowledge both through training centres and on board the vessels. Nautical Institute from London is responsible for the certification of Dynamic Position operators and training centres [9]. The process itself comprises the following phases [9]:

- Phase 1: Completion of DP basic / induction course in a training centre certified by Nautical Institute
- Phase 2: Practical on-board experience of familiarization with the DP system for 30 days, where one day is defined as the minimum of 2 hours working on the system.
- Phase 3: Completion of DP simulator course in a certified training centre
- Phase 4: Practical on-board experience of 180 days with DP system (2 hours = 1 DP day)
- Phase 5: Issue of Full DP Certificate by Nautical Institute for the validity of 5 years.

Obtaining the Full DP Certificate is a long-term process that may take few years. Possession of a Full Dynamic Positioning Certificate is a great recommendation and can greatly facilitate getting of a job on these vessels. There are many training centres around the globe that can provide initial and simulator training required to issue these certificates. Currently, the nearest ones to the Montenegrin training centres are located in Croatia. The Maritime Faculty of Kotor has the necessary equipment for these courses, while the centre itself is inactive.

Furthermore, the rules stipulate that at least one crew member of the vessel with a dynamic positioning system must possess a DP Maintenance Certificate[9] [13]. This is usually the Chief Engineer or the vessel's electrician. The approved training centre that can issue this certificate nearest to Montenegro is located in Croatia.

4. DISCUSSION

If the seismic survey and experimental wells give positive results on the existence of commercial oil reserves in Montenegro, the next phase of drilling process and oilfield construction phase could be started, which can open new employment opportunities for domestic seafarers and offshore workers.

The lack of information on the number and structure of Montenegrin seafarers is a major problem for all analyses related to this issue. According to the information from Union of Seafarers Montenegro, as one of the two trade unions of seafarers, it is assumed that there are up to 7000 active seafarers in Montenegro, mostly officers.

As Ministry of Transport and Maritime Affairs of Montenegro do not have the exact number of marine officers, the analysis has been conducted according to the number of CoCs (Certificates of Competency) issued from 2015 to 2018 by the Harbour Master's Offices in Montenegro (Kotor and Bar) and the following data have been obtained.

Table 1 Valid STCW Certificates of Competency issued in Montenegro [14]

Certificates of Competency (CoCs)	*Year 2015*	*Year 2016*	*Year 2017*	*Year 2018*
Kotor	1205	1541	1063	842
Bar	737	1327	1238	731
Total per year	1942	2868	2301	1573
Total valid certificates	8684			

Each candidate for an officer's certificate who qualifies under the provisions of STCW Convention and successfully completes the appropriate examination will be issued a Certificate of Competency. This document is issued to masters, officers, radio operators and ratings forming part of a watch who meet the standards of competence relevant to their particular functions and level of responsibility on-board. The certificates under STCW have various limitations and tonnage thresholds that apply [15] .This certificate states that the officer has been found duly qualified in accordance with the provisions of STCW and in the format prescribed by STCW for those officers qualified to receive STCW certificate [16].

According to unofficial data, up to 200 Montenegrin seafarers are employed in the offshore industry, over 80 percent of which are marine engineers. The majority of the seafarers are employed on service ships, anchor handlers and supply boats, while the number of those employed on oil drilling and production plants is negligible and ranges from 10 to 15 percent of the total number of Montenegrin seafarers employed in offshore.

Practically speaking, the number of Montenegrin seafarers is negligible compared to the total number of seafarers employed in the offshore oil and gas industry (3 to 5 present), although in offshore industry our seafarers are generally provided with better contracts in terms of the salary and duration of the sea contract. One of the reasons for a small number of Montenegrin seafarers when comparing with the general participation of our seafarers in the maritime industry can partly be explained by strict and specific requirements for employment in this part of industry, in addition to general maritime knowledge, experience and certification.

Another and more contemporary reason for a small number of our seafarers is a direct consequence of the recent oil crisis of 2014/2015, during which thousands of offshore employees lost their jobs, and hence the labour supply has been largely exceeding the market demands.

The lack of interest and inclusion of the Montenegrin seafarers' unions and organizations in this matter has the consequence that the concession agreements on the exploration and potential exploitation of oil signed by the state administration and oil companies for the total of 6 exploration blocks do not include the obligation to employ a certain percentage of Montenegrin seafarers or offshore workers. The seafarer's unions and organizations of developed countries, such as, for example, USA and Australia, have convinced their state administrations to oblige the oil companies to provide employment for even 100 percent of domestic labour in certain segments. Practices from less developed countries (ovdje treba navesti zemlje primjere) that are not able to provide expert coverage for all the positions, as it is the case with Montenegro, is that oil companies are obliged to employ a certain percentage of domestic labour by specific areas.

The signing of two concession agreements without the obligation to employ domestic labour for the total of 6 blocks for the next 30 years of the agreement duration means that Montenegro has widely missed the opportunities for priority employment of its seafarers in case of oil discovery.

5. CONCLUSION

In order to resolve the problem regarding the low number of local seafarers in offshore industry, the first step could be to activate maritime trade unions and organizations in Montenegro for persuading the state administration to upgrade future concession agreements with the obligation to employ domestic seafarers. This way, oil companies would be forced to employ seafarers from Montenegro and additionally provide them with specialized trainings at training centres of the world. After gaining the practical experience, the competitiveness of domestic labour force will be increased both in Montenegro and abroad. Also, an additional measure to be undertaken is the introduction of relevant training programs to Montenegrin maritime educational institutions in order to offer readily specialized seafarers and students to the oil companies, which would greatly increase their employment opportunities in this sector.

REFERENCES

[1] Ministarstvo Ekonomije Crne Gore (2013), Montenegro offshore hydrocarbons exploration and production program draft version

[2] IFP school, the graduate school for energy and transportation profession (2014), Three main steps oil & gas field development

[3] Marine insight, offshore vessels, https://www.marineinsight.com/types-of-ships/what-are-offshore-vessels/

[4] IMCA (2008), Guidance on basic safety training and vessel induction for non-marine personnel working offshore

[5] PetroWiki, Offshore rig crew, https://petrowiki.org/Offshore_rig_crews

[6] Maersk drilling, https://www.maerskdrilling.com/en/jobs-and-careers/explore-the-different-offshore-positions

[7] IMO (2014), Resolution A. 1079 (28) Recommendation for the training and certification of personnel on mobile offshore units (MOUs)

[8] Merchant navy web site jahajee, Merchant navy ranks https://www.jahajee.com/Merchant-Navy-Ranks/

[9] IMCA (2012), DP operator the facts, IMCA download 10120 (Dynamic positioning (DP) operator)

[10] Azara crew agency, https://www.azara.hr/index.php/en/vacancies

[11] Xijiang oil field South China Sea FPSO lease contract Lufeng development company and contractor and ConocoPhillips China Inc. Company, 20th October 2003

[12] IMO (2010), MSC-MEOC.2/ Circ.9 25 Guidance for the application of safety, security and environmental protection provisions to FPSO and FSU

[13] IMCA (M 117 Rev. 2) Guidelines for The Training and Experience of Key DP Personnel, 2016

[14] Ministarstvo saobracaja i pomorstva Crne Gore, Nataša Maraš, Samostalna savjetnica za slobodan pristup informacijama (2019).

[15] International transport workers federation; STCW A GUIDE FOR SEAFARERS, Taking into account the 2010 Manila amendments, 49-60 Borough Road, London SE1 1DR, UK, pdf fail.

[16] https://www.palaureg.com/core-services/seafarer-division/certificate-of-competency-coc/

WAYS OF REDUCING THE CONTENT OF CATALYTIC FINES IN MARINE HEAVY FUEL OIL

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Summary

Undisturbed operation of the ship's propulsion plant requires quality fuels derived from crude oil through the processes of separation, transformation and treatment in refineries. The process of transformation implies the catalytic cracking where a catalyst is used to break down larger, complex hydrocarbons into simpler molecules containing less atoms of carbon per molecule. This is achieved by means of the catalysts as hard forms of aluminium and silicon oxides. The transfer of these catalytic fines into fuel is inevitable and, as they are extremely abrasive compounds, they have to be removed from fuel before causing serious damage to diesel engines. There are a number of preventive measures that have to be professionally planned and performed on board ship before the fuel is injected and atomized in the engine's combustion chamber. The last aspect of preventing damages to marine engines refers to the selection of quality materials for piston rings and the implementation of new technologies that assist in diagnosing the condition of engines. All the above mentioned actions are necessary to ensure smooth engine operation and reduce damages and considerable related costs caused by catalytic fines in the heavy fuel oil.

Keywords: fuel treatment, piston ring materials, abrasive wear, diagnostic tools, catalytic fines.

1. INTRODUCTION

New international environment regulations on reduced content of sulphur in fuels and, therefore, increased level of cracking, come into force as from 2020, it is assumed that fuels will contain even more impurities likes cat fines[1]. In refineries, crude oil passes through the processes of separation, transformation and treatment. The processes of separation are known as the primary, while the processes of transformation and treatment are known as the secondary processes. The separation, i.e. primary processes, where hydrocarbon molecules do not change in size or structure, comprise unit operations of the atmospheric, vacuum, extractive and azeotropic distillation, of which the atmospheric and vacuum fraction distillations are the most important. The secondary processes are chemical actions that change the size and/or structure of hydrocarbon molecules, thus increasing the product quality by 30 to 35%, in gasoline and diesel fuels in particular. In addition, gasoline octane and diesel cetane values are higher, thermal stability… The transformation processes are the catalytic cracking processes in the refineries where a catalyst is used to break down complex hydrocarbons into simpler molecules (steam and catalytic cracking).

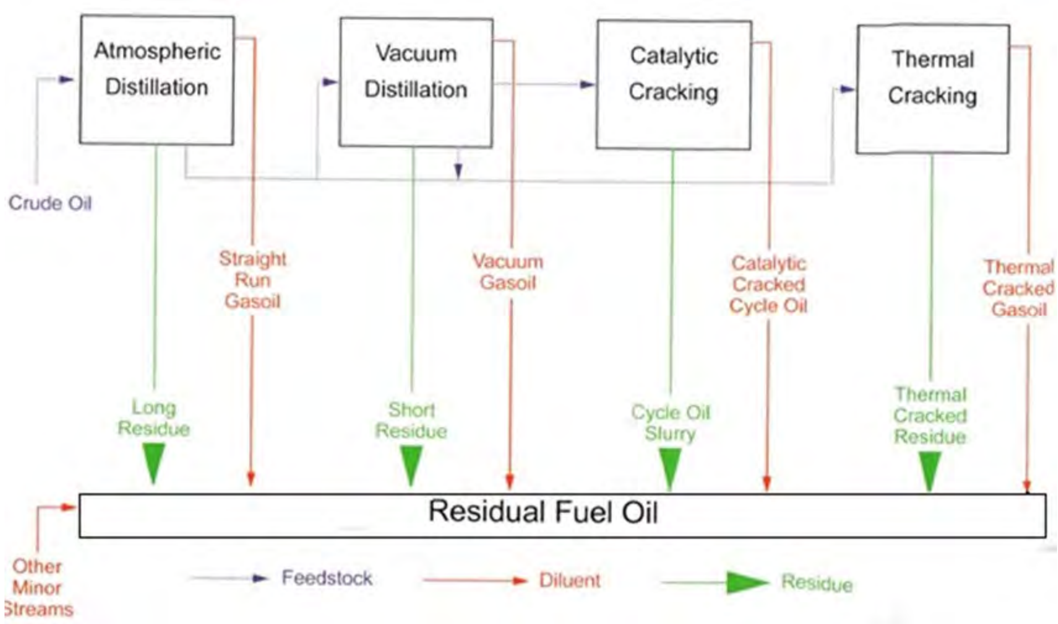

Figure 1 Residual fuel oil production [2]

During the process of catalyst-aided cracking, the very fine catalysts parcrticles, composed of aluminium and silicon oxides are crunched. They have various micro sizes and shapes, and it is very difficult to separate them from fuel. The crunched catalysts undergo the process of refinement and enter via the bunker barges into the ship's bunker tanks. Continuous use of catalysts cause their degradation into fine particles. Some of them remain in the fuel and may cause serious problems, as these catalytic fines are very hard and abrasive. In the Mohrs hardness scale ranging from 1 to 10, where diamond measures 10, the hardness of cat fines (Al+Si) amount to approximately 8 [3]. Marine residual fuels have to comply with ISO 8217:2017 (Table 1). According to this standard, fuels that are commonly burned in marine engines can have maximum 60 mg of catalytic impurities per 1 kg of fuel, while the engine manufacturers allow the maximum content of 15 mg/kg prior to entering the main engine. Even so, there is a risk of abrasive wear of the piston rings and cylinder liners (with amount of 15 mg/kg of catalytic impurities per 1 kg of fuel) . Although refineries are able to deliver fuels having less than 15 mg/kg of catalytic fines, they may choose to meet the less stringent ISO standard. Price could be the main reason because the costs of refining processes are high. It is very likely that the availability of fuel would be restricted globally should the ISO standard be more stringent, and this would result in increasingly serious problems in the global shipping industry [4]. On the other side, the shipping companies themselves are prone to use cheaper and more cost-effective fuels.

Table 1. Limits of fuel contents must meet ISO standard 8217:2017 [5]

Limits	Parameters (units)	RMA 10	RMB 30	RMD 80	RME 180	RMG 180	RMG 380	RMG 500	RMG 700	RMK 380	RMK 500	RMK 700
Max.	Aluminium + Silicon (mg/kg)	25	40		50	60						

In addition to efficient liner lubrication, proper selection of lubricating oil and normal operating conditions, it is necessary to select adequate piston ring material able to withstand the effects of catalytic fines that may enter the combustion chamber via scavenge air and primarily via fuel injection system. Also, there are well-known recommendations for reducing these impurities in ship's engine systems [6]: efficient analysis of the ship's fuel, cleaning the fuel tanks, equipment maintenance, crew training, fitting low and high suction lines to the settling and service tanks, efficient separation and filtration of fuel. Moreover, some companies perform fuel sampling before and after the fuel separator for monitoring its performance and, if and when necessary, for engaging another separator [7] or switching to diesel fuel as a measure of prevention maintenance.

2. SYSTEMS OF SHIP'S FUELS, THEIR TREATMENT,CONSUMPITON AND ANALYSIS

The marine fuel system can be divided into three parts. The first part refers to the moment when new fuel is bunkered on a ship's bunker/storage tanks (figure 4). The second one is when fuel is ready for use (passing through a series of fuel filters and separations system) and ultimately when the fuel enters in the engine through fuel pumps and fine filter. In 2017, it has shown an increase in the number of fuel quality problems on the American and European continents, equally for distillates and residual fuels. If this trend continues, it can be concluded that by 2020, there will be an even greater number of "bunker alerts", which means that fuel quality will continue to pose a problem for the world's fleet, ship's crew and the natural environment.

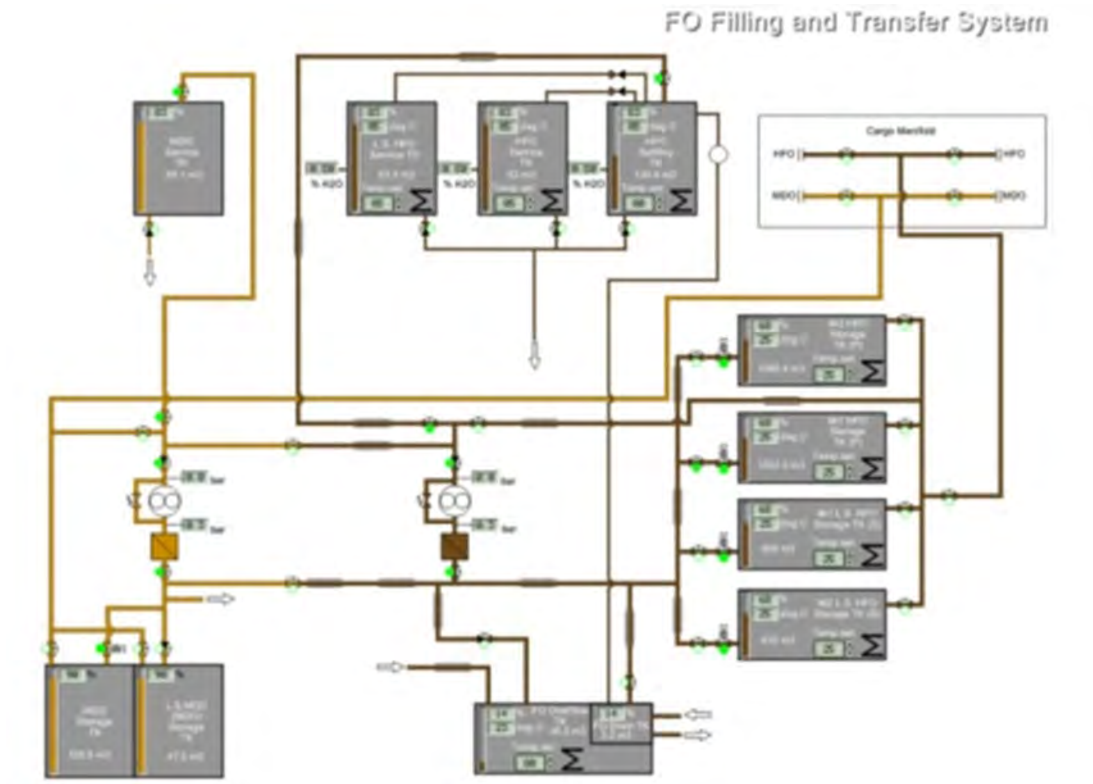

Figure 2 System of the ship's bunker and storage tanks [8]

The ship's fuel system requires a number of measures that are taken in order to decrease the risk of damage to the engine due to catalytic fines:

- Enhance ISO Standard 8217 and reduce the maximum allowed amount of catalytic fines;
- When possible, clean the accommodating bunker tanks and wash the bunker line;
- Before bunkering, use additives to improve the process of fuel separation and filtration;
- Use adequate procedure to sample bunker fuel;
- Have the sample analysed by an internationally recognised laboratory and wait for the report;
- If possible, start to store and use the fuel after the laboratory report has confirmed that the fuel is of good quality (by receiving/requesting certificate of quality of new bunkers);
- Perform on-board analysis of the fuel if the independent analysis (equipment) is available;

- Warm up the fuel properly for efficient separation;
- If the ship is fitted with fuel analysis tools, it is essential to analyse the fuel after draining from bunker tanks, after settling and draining in the settling tanks, before and after (regularly maintained) separator, and immediately before entering the main engine (this paragraph is in line with second above should be selected only one) ;
- Regularly drain fuel tanks;
- Handle the fuel separators properly and, when needed, engage the second separator in case the fuel analysis indicates high percentage of fuel impurities, and pay close attention to the flow of fuel through the separator, its temperature and time of removing impurities from the processed fuel;
- It is desirable that the settling and service tanks are fitted with the so-called low and high suction lines;
- Use modern separators that are efficient in removing catalytic fines from fuel;
- Use modern automatic filters featuring the possibility of additional removal of cat fines;
- Unless available by the original design, modify the overflow pipe so that fuel flows from the bottom of the service / daily tank (where the level of cat fines are the highest) back into the settling tank (Figure 5).

All these actions are essential to prepare the fuel system adequately for supplying good fuel for combustion in the main engine.

Figure 3. Onboard fuel treatment by percentage [9]

3. METHODS AND EQUIPMENT FOR IMPROVING THE FUEL TREATMENT ON BOARD SHIP

3.1. Use of chemicals for improving the fuel separation and preventing the formation of sediments at the tank bottom

It is recommended that fuel is treated with additives prior bunkering in order to improve the properties and the process of separation. Adequate blending of additives and fuel is possible through the sounding pipe or the pre-installed dosage system, following the recommended calculated (mixing) ratio. For instance, the use of Wilhelmsen / Unitor product *Fuel Power Conditioner* [10] provides a number of benefits such as stabilisation and homogenisation of fuel, efficient process of the separation of impurities, and lower generation of deposits in the separators. There are no chemical treatment products on the market, which can directly neutralise catalytic impurities and remove them from fuel due to their extreme hardness, but indirect actions can enhance the operation of the systems designed to remove these fines, such as separators, filters, settling tanks, and non-permitting the formation of sludge in tanks. Other manufacturers supply similar products, e.g. *Vecom FOT Sludge Dispersant* [11]. Some chemical additives, i.e. detergents and de-emulsifiers, ensure certain fuel properties that are hard to obtain by using onboard fuel cleaning systems without compromising other properties of the fuel [12].

3.2. Disc stack separators

These separators are commonly used on board ships. They consist of a large number of components of which the most essential are the stainless bowl and discs. The number of discs varies from 50 to 150 and their clearance between 0.4 to 2.0 mm, depending on metal distancers fitted to the top of each disc. The top disc has a larger diameter compared with others. When opening and cleaning the bowl it is necessary to check whether they are broken or cracked. Their smooth surface allows sliding of particles and water at the revolving speed of 4000 to 9000 min-1. Lower speed centrifuges are used for separating heavier particles, while higher speed separators are used for removing relatively lighter particles [2]. There are typically two or more fuel separators on board, depending on the design and size of the vessel, and on the fuel consumption. They can be engaged in parallel or serial operation. Experiments have indicated that the removal of catalytic impurities from residual fuels is most efficient when the separators are engaged in serial operation.

One of the parameters that can be adjusted to improve separation is the viscosity of fuel. As the fuel temperature rises, the viscosity decreases. If the temperature drops to 90°C, the flow must be reduced to 72% of the nominal flow in order to maintain the separation efficiency as it is when the temperature is at 98°C. At 85°C, the flow should be reduced to 50% [13].

The following graph shows what might happen if the temperature falls and the flow remains the same.

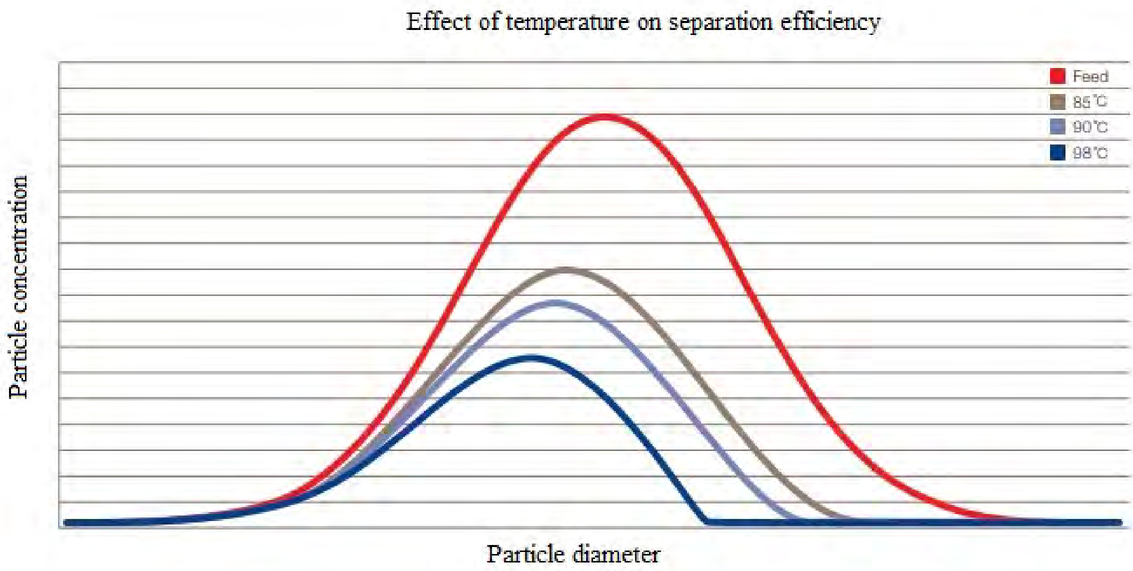

Figure 4. Efficiency of fuel separation at various temperatures.

The red curve indicates the concentration of particles at the entrance, whereas other curves show the concentration of the particles at the outlet of the separator at the temperatures of 85°C, 90°C and 98°C [13]. It seems to be reasonable to take into consideration the separation at temperatures higher than 98°C as it is obvious that the separation efficiency increases with fuel temperature. However, it is worth noting that the 98°C limit has been set for safety reasons (to avoid evaporation and loss of water seal and operating water for bowl closing). If the safety conditions could be controlled, the separation temperature of 115°C would result in the increase in flow by 80%, maintaining good performances. In other words, maintaining the flow at higher temperatures would increase the efficiency of separation.

Fuel transferred into the ship bunkers has typically around 60 ppm Al+Si and must therefore be cleaned through the settling tanks, separators and filters (Figure 9). As the protection device, there is a fine mesh filter (installed) just before the engine, able to deal with the smallest impurities (depending from mesh size). Being one of the essential elements of the fuel system, the engine should not be operated without it. Its maintenance and cleaning, however, are not easy. Common (cleaning) methods applied to a 10-micron filter are not efficient so that ultrasound baths with adequate solvents are recommended.

3.2.1. GEA Westfalia Separator, CatFine Master

GEA Westfalia, one of the major manufacturers of marine separators, claims that their ship separators ensure optimum removal of (catalytic) fines and maximum quality of fuel (separation). Easy to handle and meeting the strictest safety standards, these devices might be the long-term solution to dealing with fine solid impurities, especially with regard to the uncertain future quality of the marine fuel (2020 IMO fuel requirement) that is stored in ship bunkers.

Numerous studies of cylinder and piston ring wear indicate that in 90% of the cases the rapid wear results from fine particles stuck on the liner's surface. Even within a relatively short period of time, damage to the cylinder inner parts occur due to presence of impurities in the combustion chamber. Their presence arises from residual particles in fuel tanks and inefficient fuel treatment on board ship. In order to efficiently separate fine impurities from fuel and thus protect the vulnerable engine parts, GEA Westfalia claims that the maximum size of these particles should be 3 µm at the maximum level of 5 ppm in fuel. The only way to determine the efficiency of separation of catalytic fines is the CFR (Certified Flow Rate) method, which is expected to become an ISO standard [14]. Separators produced by this manufacturer have the so-called Type Approval Certificate issued by DNV-GL [15].

As the higher temperatures result in reduced viscosity and density of a fluid (Stokes' law), the rate of sludge forming in the separator is increased. In this way it is much easier to separate even the finest particles that would otherwise remain in the fuel. The specific feature of the type of separator is the optimisation and the operating temperatures up to 110°C in order to have maximum benefits from this effect. Also, lower flow rates in the separator units imply an extended separation time, which is additional feature for achieving efficient separation.

There are two ways to meet higher standards in fuel cleaning on the ships that are already fitted with Westfalia separators:

- Upgrading the existing equipment produced by GEA Westfalia Separator Group;
- Adjusting and improving the other existing separation equipment.

GEA Westfalia Separator is a modern e-type self-cleaning separator. Fitted with a patented sensor system for automatic monitoring of water and solids, it ensures the highest fuel quality (separation) even in extreme sea conditions. The system is fully automated and can perform without surveillance, and is able to eliminate errors by means of manual adjustments. The water content is checked and controlled by Water Monitoring System (WMS), while the Sludge Space Monitoring System (SMS) monitors the space with separated solids such as catalytic fines, sand, abrasive matter and rust [14].

The automatic discharge of impurities from the separator bowl is performed at a precise and graduated rate to avoid the loss of fuel. GEA Westfalia Separator Hydrostop is a hydraulic device that regulates the timing of discharging the impurities over extremely short periods, with maximum outlet diameter and minimum fuel loss. In this way, the high concentrations of solids are discharged efficiently. Malfunctions or irregular operation of the fuel separator, or an inadequate selection of the separator, may result in irregular separation i.e. insufficient separation of impurities from fuel. Poor quality of fuel may cause a number of issues, including:

- Unstable fuel system;

- Damage to the engine due to late fuel ignition and excessive wear;
- Health and safety risks for the crew due to waste products;
- Environmental issues (emissions of NOx, SOx, etc.).

Solids in heavy fuel oil include dust, soot, ashes, metals, etc. These particles remain dispersed in the air and gradually settle on the surface due to gravitation [7].

3.3. New types of filters dealing with catalytic fines

Besides separation, filtering of fuel is essential on board ships. Fuel filters are typically placed immediately before the fuel pumps and flow meters. However, fine abrasive impurities are removed by the filters fitted just before the engine. They are often of the *duplex-fine* type. Practical experience has proved that the cleaning of a 30-micron filter is a difficult task due to asphaltic matter settling on the mesh holes. Normal functioning and maintenance of 10-micron filters [13] require an *ultra-sonic* device [16] that uses necessary chemicals, in order to clean the filters efficiently, as the conventional manual cleaning is inefficient.

Alfa Laval has produced an automatic fuel filter whose nominal fineness for heavy fuels amounts to 10-30 μm, with the absolute fineness ranging from 25 to 45 μm. Figure 5 shows a fuel system with a likely position of this filter.

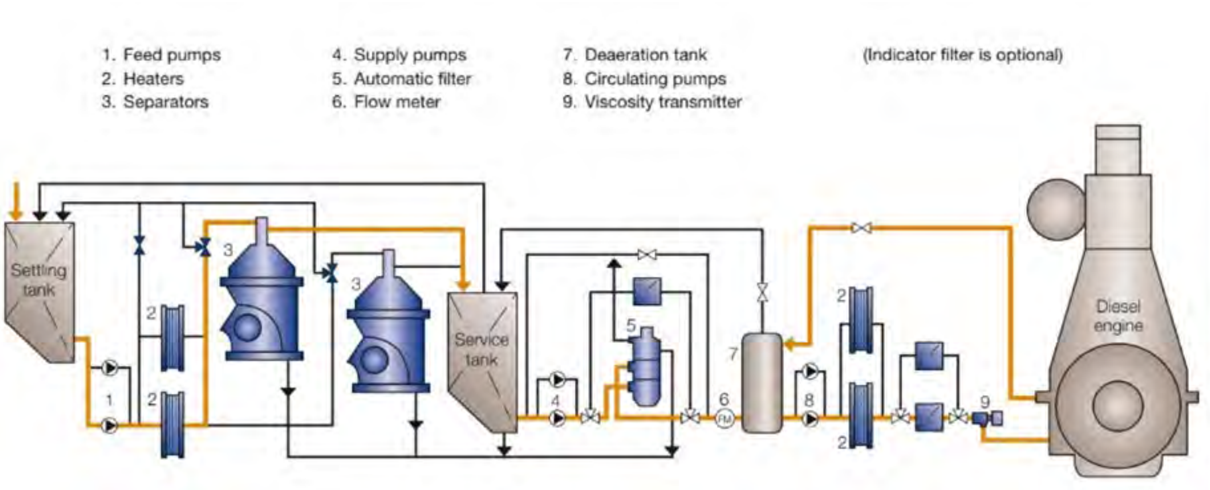

Figure 5. System of fuel filtering on board ship (possible positioning on the so-called cold and hot sides of the system) [17]

3.4. Fuel analysis on board and ship laboratory

3.4.1. Mobile laboratory for fuel analysis

Special tools are used for quick fuel analysis on board ships. Figure 6 shows an example of the ship's portable fuel analysis kit.

Figure 6. Fuel sampling kit [18]

Figure 7 shows various samples indicating the real amount of impurities after the fuel analyses.

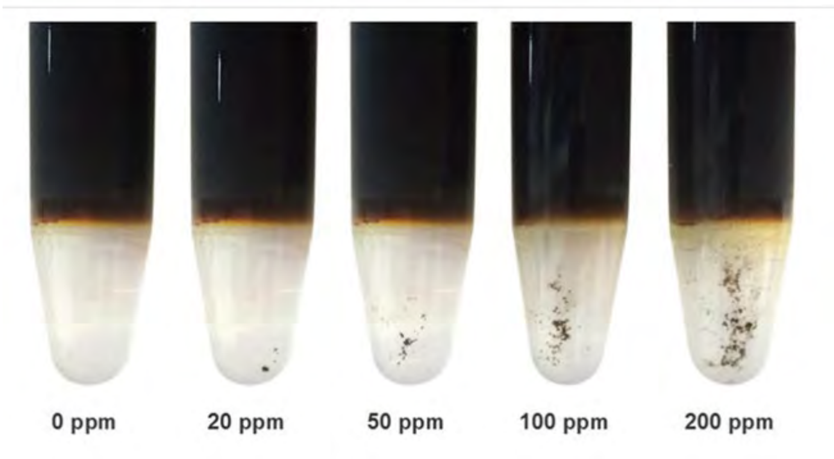

Figure 7. Samples of the fuels containing catalytic fines [19]

3.4.2. Stationary equipment for fuel analysis on board ships

In addition to the portable kits, there are stationary devices on board ships, which can perform fuel system analysis at any time. This is essential as the system or its specific components can be regularly monitored. If a company/(management) is not able to install such equipment, fuel samples can be taken from vital positions and sent to laboratories for analysis, as shown in Figure 8.

A good ship management implies a continuous monitoring of the fuel analysis systems that check the fuel samples before and after the separators, depending on the quality of fuel. If a high quality fuel is used, an analysis of all elements should be performed at least once in four months. When it is known or suspected that the fuel quality is reduced, analyses should be performed more often. It is always helpful to have insights into fuel consumption, efficiency of individual components and fuel cleaning elements. Samples taken while the fuel is being used also assist in assessing the efficiency of the fuel cleaning components and allow preventive measures to be taken where necessary.

The basic purpose of the fuel check system is to monitor and timely assess the efficiency of all components of the fuel treatment system. The crew take the fuel samples and send them to one of the internationally recognised licenced laboratories. Sampling must be carefully carried out, involving all vital positions within the fuel system. The experts at the shore-based laboratory examine the samples and forward the results to the shipping company and the ship. If necessary, additional guidelines are given for the exploitation of the propulsion systems. These instructions have to be carried out by the chief engineer.

Studies have indicated that, in addition to the amount of cat fines, it is important to find out their size. One of the first commercial products designed to perform this task is the CSD (*cat fines size distribution*) tool. This method is very useful in assessing whether the onboard fuel treatment has been efficient in removing the impurities of all sizes.

The FSC (*Fuel System Check)* program is able to detect likely problems during fuel centrifuge operation. It allows the crew to address the problem on time or to switch to a higher-quality fuel containing without cat fines.

Test Results

Port Singapore JAN.-.2019.

	Unit	Reference	Transfer Pump	After Separator 1	After Separator 2	Before M.E.
Density @ 15°C	kg/m3	988.8	988.5	988.6	988.5	988.5
Viscosity @ 50°C	mm2/s	316.8	311.6	320.4	320.1	319.6
Water	%V/V	0.17	0.15	0.08	0.08	0.08
Sulfur	%m/m	3.01	3.11	3.04	2.98	3.01
Aluminium + Silicon	mg/kg	59	54	6	6	10

Port Elizabet DEC.2018

	Unit	Reference	Transfer Pump	After Separator 1	After Separator 2	Before M.E.
Density @ 15°C	kg/m3	987.6	984.2	984.1	984.1	983.9
Viscosity @ 50°C	mm2/s	365.2	391.7	393.5	393.9	390.2
Water	%V/V	0.20	0.20	0.19	0.17	0.17
Sulfur	%m/m	1.79	1.88	1.88	1.90	1.79
Aluminium + Silicon	mg/kg	52	41	12	11	14

Figure 8. Tabular display of the FSC efficiency check for fuels with various contents of sulphur and cat fines (Veritas Petroleum Services BV) [20]

When comparing these two cases, it can be noted that the content of cat fines can be reduced by means of settling tank drainage, depending on the separator performance (the efficiency of removing the impurities ranges from 71% to 89%. In both cases, an additional separator was used in parallel operation because of high contamination of cat fines in the bunkered fuel. The outlet of the second separator showed almost no change i.e. no further reduction of the cat fines, but in both cases their amount slightly increased just before the main engine (3-4 mg/kg). This may imply that the cleaned fuel after the separator was contaminated on the way to the main engine (through the service tank, mixing tubes, venting box or in filter casings). It is therefore essential to clean these components periodically to avoid the accumulation of impurities. Contamination within the piping system is not possible as the fuel flow at high velocity and the pipe walls are washed efficiently. Regular drainage of the mixing tubes is recommended, along with the adequate cleaning of the filter casings. This procedure indicates the reasons for gradual improvement of fuel properties from the settling tank to the separator outlet, as shown in Figure 3, and represents one of the ways for analysing the fuel system efficiency.

Another solution is to install the NMR (*nuclear magnetic resonance*) sensor system that is able to perform on-line measurements, with the results available at any time (Figure 9). The system is robust, mobile and rather cheap [21], so that it represents a very cost-effective solution if damages to the main engine can be prevented.

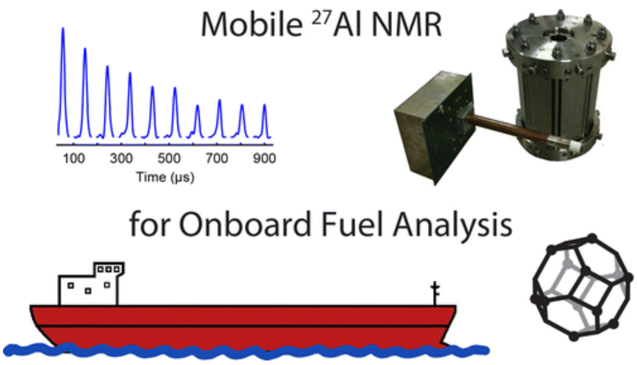

Figure 9. NMR sensor for marine fuel analysis

In addition to the above discussed systems, ships can use the co-called *CatGuard* equipment – an online system for monitoring the content of catalytic fines in fuel (Figure 10). Depending on the type and make, the system can be connected to one or more positions in the fuel cleaning system, e.g. before the main engine, before and after the separator, etc. [22] The advantage of this system lies in the ability to establish the amount of impurities at any position and at any time, and take preventing measures for their removal.

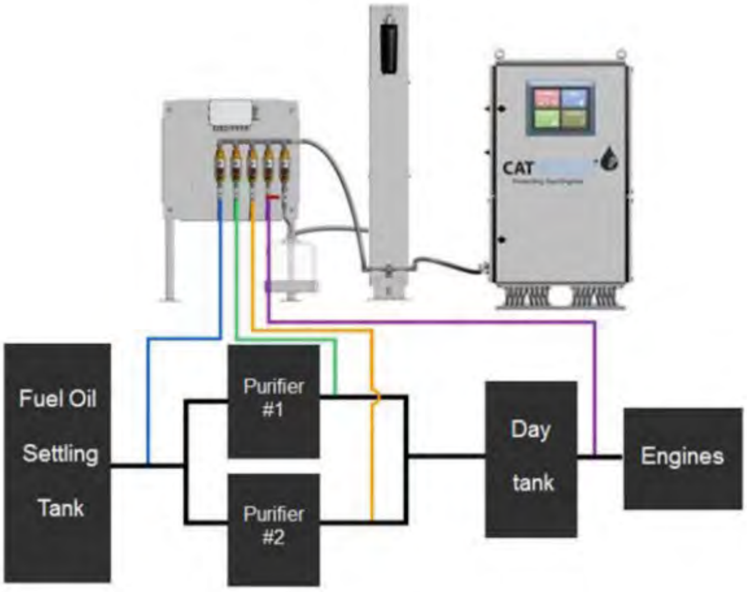

Figure 10. Installation scheme of the CatGuard system for monitoring cat fines [6]

Figure 11 shows the validity of the *Cat Guard* analysis system, confirmed by the testing in laboratory 2 and using FOBAS' analysis (*Fuel Oil Bunker Analysis and Advisory Service).*

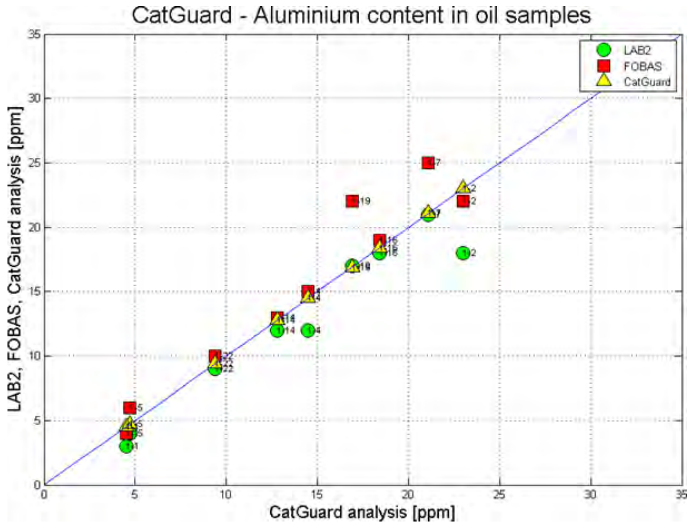

Figure 11. Aluminium content in fuel oil samples measured by Lab2, FOBAS and CatGuard analysis [23]

The above discussion implies that it is essential to perform the education and training of the crew, regular examination of the fuel systems and their components, checking the efficiency and maintenance of all elements in the fuel cleaning systems, in order to protect the engine against excessive wear, extend the life of the engine, reduce the consumption of fuel and reduce costs.

4. COST ARISING FROM THE DAMAGES CAUSED BY CATALYTIC FINES IN FUEL

There are numerous examples of damages caused by cat fines and their abrasive action, when the impurities enter the engine cylinder and get stuck on the liner surface, between the piston ring and its groove, or when they are thicker than the lube oil film on the liner wall. The marine two-stroke main engine may suffer the wear of all cylinder liners due to cat fines action after only 100 working hours or, in other words, after just 4 days. [24] In two different cases involving two major engine manufacturers, the damage resulting from the excessive wear due to catalytic fines amounted to 900,000 $ and 1,500,000 $ respectively [25] or, as estimated by [26], 300,000$ and 1,500,000 $ respectively. The damages affected both the shippers and the insurance companies.

The cost of the main engine repairs amounted to 500,000 $ [27] with additional costs related to the fact that the vessel was out of service during the period of repairs. At this point, it is worth noting the charter costs. For a realistic estimation of the charter price, which varies on monthly basis, the Allied Shipping Research analysis has been used. In April 2018, the daily charter costs for a VLCC tanker were about 20,000 $, while the costs for chartering a Suezmax tanker were somewhat lower, amounting to around 15,500 $ per day, provided that the vessel was chartered over a period of one year [28].

Quite obviously, in case of damage to the main engine, the shippers may face losses amounting to half a million dollars, or much more.

5. CONCLUSION

As the catalytic impurities are inevitable in marine fuels, it is necessary to pay close attention to their presence and the reduction of their contents. These particles are very fine and easily find their way to the combustion chamber via the (fuel) injector. The ensuing issues and damages to the engine parts are likely to result in huge costs. At the first line of defence is the shipper / manager who is responsible for selecting high-quality fuels from recognised suppliers in order to minimize the subsequent adverse effects of the fuel impurities. The task of that person is to obtain, in the stage of quoting, the offers from several suppliers, to evaluate their (bunker) products' certificates of quality, and to select the best value for money.

Many shippers / managers tend to make savings and avoid the installation of the equipment that can improve the efficiency of the separation of cat fines from fuels. Likewise, shippers or managers may try to avoid installation of the equipment for monitoring the efficiency of fuel cleaning systems and tools, relying instead on the experience and quality of the crew. This is a very questionable and risky decision, considering the staff fluctuation and their varying qualities. Moreover, shippers and managers do not invest enough funds and time in specific training of the crew members who have to be familiarised with the cat fines reduction tools and methods, in order to address the problems and risks related to the adverse effects of the fuel impurities.

The ship's crew has to endure the proper implementation of the procedures designed by the (company) *Safety Management System* (SMS) and manufacturers' recommendations. The recommendations typically consist of the following activities:

- It is important to avoid mixing two different bunker fuels in the same bunker tank, i.e. the goal is to store new fuel into an empty tank. If mixing of fuels cannot be avoided, the ratio new/old should be reduced to minimum. Mixing may generate instability of the fuel, which will consequently have adverse effects on the removal of catalytic fines.
- For safety reasons, the new fuel should not be used before obtaining its laboratory analysis. If the results reveal poor properties of the fuel and non-compliance with the ISO specifications, the fuel should be discharged from the ship's bunkers (tanks) as agreed with the shipper / manager.
- Apply chemical treatment before bunkering, with the purpose of improving the quality of fuel, its homogenisation and more efficient separation of the cat fines.
- If it is possible to use two settling tanks on board the ship, they should be used alternatively, so that one of them is in use while the other is filled with fuel that requires some time to become settled and drained. This would further facilitate the effect of settling and removing impurities from the tank bottom.
- Drainage from settling and service tanks, which is accumulated in a dedicated tank, must not be pumped back into the bunker or settling tanks as it does not make sense to return the impurities into the system once they have been drained and eliminated.
- The process of accumulating catalytic fines is constant as it is not possible to eliminate the impurities altogether through drainage and separation. It is therefore important to perform periodic cleaning of all tanks by reducing the standard time interval from 5 to 2.5 years, and even less when (deemed) necessary.
- In case the high suction line from the settling and service tanks has not been provided, it should be installed and regularly used in bad weather and in case the laboratory analysis confirms an increased content of cat fines.
- The (fuel service) pipeline system, running from the service tank to the consumers, should be periodically drained and adequately cleaned, (return/mixing tube) and filter casings, as the points where cat fines may accumulate over time.
- In case the permanent cat fines monitoring system has not been provided, it is important to take fuel samples from various positions (transfer pump, before and after the separator, service tank, entrance to the engine) in order to monitor the efficiency of fuel cleaning operation (system) and to apply timely corrective measures. [29, 30]
- Close attention should be paid to the separators that most contribute to the removal of abrasive cat fines. If the shipper / manager cannot install new separators on board ships, the optimum performance of the existing separators should be ensured through regular checks and maintenance, according to the manuals. It is worth noting that the highest level of the elimination of impurities is

achieved at the lowest possible fuel flow and at the lowest fuel viscosity (implying the temperatures up to 115°C), taking into the consideration that the above parameters are constant, i.e. without fluctuations. Adequate spare parts for the separators should be available on board due to unpredictability of the issue, with the purpose of ensuring continuous and efficient operation of the separators.

- Since filtering is also important, the special focus should be on the manufacturers' recommendations regarding the installation of 10-micron filters before the engine. This will become a standard in future designs, but it is advised to fit the existing vessels with modified filters. Their function is defined not as the primary means of eliminating catalytic and other impurities, but as the secondary and the last fuel cleaning elements, placed immediately before the engine.
- It is crucial to monitor the state of the liners, pistons and rings through regular inspections that should be more frequent when using new fuel or prior to using it. If the fuel contains a large amount of catalytic impurities, inspections at every port of call are recommended. There are advanced tools that can be quickly applied (without dismantling the cylinder cover) for measuring the diameter of the liners and monitor the condition of these parts at regular intervals.
- Many Marine Main engines are fitted with sensors for monitoring the temperature of the cylinder liners so that potential problems related to fuel impurities can be detected early (when is noted temperature rise above normal of cylinder liners). Corrective and preventive measures can then be taken to prevent damages to the engine.
- It is possible to regularly monitor oil drainage from the engine (underpiston space) and send samples for the laboratory analysis with the purpose of establishing the contents of ferrous and chromium particles, as well as the oil viscosity for each cylinder. This enables timely and efficient reaction if the readings are alarming. Another aspect of monitoring is highly recommended by manufacturers and has been very useful in practice. There are sensors for permanent installation, able to constantly read the ferrous contents in drainage oil for each cylinder separately, showing the real conditions and enabling quick response and prevention of damages to the engine due to abrasive particles in fuel.

Safe and smooth engine operation that is not affected by the negative effect of abrasive catalytic fines can be achieved only through the synergy of the above discussed procedures. The initial careful selection of adequate (bunker) fuel should be followed by correct procedures and professional control of the onboard fuel cleaning systems and by continuous monitoring of the ship's engines by various monitoring systems.

REFERENCES

[1] The International Chamber of Shipping (ICS); Guidance to Shipping Companies and Crews on Preparing for Compliance with the 2020 'Global Sulphur Cap for Ships' Fuel Oil in Accordance with MARPOL Annex VI, Marisec Publications, July 2019.

[2] Fisher C., Meech R.: Bunkers An analysis of the Technical and Environmental Issues, 4th edition, Petrospot Limited, England 2013.

[3] Vukičević, M., Račić, N., Ivošević, Š.: Piston ring material in a two-stroke engine which sustains wear due to catalyst fines, Vol. 70, No. 2, 2019. http://dx.doi.org/10.21278/brod70208

[4] International Council on Combustion Engines, CIMAC Guideline ISO 8217:2017 - FAQ, 03-2017.

[5] www.dan-bunkering.com (access: 12/10/2018).

[6] Rolsted, H., Charlotte, R., Ole, J., Mats, E.:PAPER NO.: 51 Onboard Fuel Oil Cleaning, the ever neglected process How to restrain increasing Cat-fine damages in two-stroke Marine Engines, CIMAC Congress 2013, Shanghai

[7] Golub, I. Antonić, R. Dobrota Đ.: Optimizacija rada sustava brodskog separatora teškog goriva primjenom dijagnostičkih metoda zaključivanja, Pomorstvo, Scientific Journal of Maritime Research 25/1(2011), pp. 173-188.

[8] Transas manual LCC tanker model of marine engine simulator, pdf.

[9] FSC Al+Si Reduction in fuel Treatmant Plant, Managing Risk by DNV, pdf.

[10] https://www.wilhelmsen.com/product-catalogue/products/marine-chemicals/fuel-oil-chemicals/heavy-fuel-oil-treatment/fuel-power-conditioner-25-ltr/ (access: 24/07/2019)
[11] https://vecom-marine.com/product-categories/fuel-oil-treatment/fot-sludge-dispersant/ (access: 24/07/19)
[12] Tireli, E.: *Goriva i njihova primjena na brodu,* Faculty of Maritime Studies – University of Rijeka, 2005.
[13] Alfa Laval AB: The Alfa Laval Adaptive Fuel Line BlueBook – Technical reference booklet, 2018 Edition, 2018.
[14] https://www.gea.com/en/binaries/BRO-MA-CatFineMaster-2014-10-EN_tcm11-23438.pdf (access: 15/04/2019)
[15] DNV-GL Certificate No: TAM00000BF Revision No:1 This Certificate is valid until 2021-12-04. Issued at Hamburg on 2018-10-24.
[16] International Council on Combustion Engines: CIMAC Guideline Filter treatment of residual fuel oils, 015-11 (1st edition)
[17] Alfa Laval: Automatic filters for fuel and lubricating oil, Technical information for oil filtration http://www.swhybj.com/Upload/2013-12/2013121111053946.pdf (access: 24/07/2019)
[18] Atkinson, D.: Determining Catalytic Fines Concentrations in Heavy Fuel Oils, MTZ Industrial Issue 1/2017
[19] https://www.wilhelmsen.com/product-catalogue/products/marine-chemicals/test-kits-and-reagents/oil-test-kits/unitor-catalytic-fines-test-kit/ (access: 24/07/2019)
[20] Fuel analysis by Veritas Petroleum Services BV from 2015, 2018 and 2019, pdf.
[21] Sørensen, M., Vinding, M., Bakharev, O., Nesgaard, T., Jensen, O., Nielsen, N.: NMR Sensor for Onboard Ship Detection of Catalytic Fines in Marine Fuel Oils, dx.doi.org/10.1021/ac5014496 | Anal. Chem. 2014, 86, 7205−7208
[22] http://www.nanonord.dk/products/catguard/ (access: 24/07/2019)
[23] http://messe.no/ExhibitorDocuments/186917/6685/FAR%20salg.pdf?ExhibitionId=557 (access: 24/07/2019)
[24] DNV: *Engine worn out in less than 100 hours by catalytic fines.* Det Norske Veritas, Classification Support. December 2010.
[25] Breamar, J. H. : JHC Report - *Marine Engine Damage due to Catalytic Fines in Fuel (Technical Analysis)*, September 2013.
[26] Alfa Laval AB. (2018). The daily grind - Cat fines and engine wear, Part 1. https://www.alfalaval.com/ (accessed: 15/01/2019)
[27] Wright, A.: Marine Fuel Quality 2015 An Objective Review (FOBAS). Lloyd's Register GMT Ltd, February 2017.
[28] Lazaridis, G.: *Allied Shipping Research*. Retrieved from Allied Shipbroking Inc. April 2018
[29] MAN Diesel & Turbo Service Letter: SL2017-638: Cleaning of Heavy Fuel Oil and Maximum 0.10% Sulphur Fuels – How to remove cat fines.
[30] IACS Recommendation 151, July 2017: Recommendation for petroleum fuel treatment systems for marine diesel engines.

TRENDS AND PERSPECTIVES OF CARGO TRAFFIC ACTIVITIES IN THE PORT OF SPLIT

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Summary

Predominately perceived as a port for both national and international passenger traffic, cargo traffic activities in the Port of Split are often marginalized despite the positive trends of cargo throughput volumes in the recent years. With the absence of significant investments in port facilities, inadequate infrastructure and insufficient cargo-handling equipment, Split cargo basins jointly handled more than 3 million tons of various commodities in 2017. The current cargo throughput levels positioned the port on the third place, just behind Port of Ploče on the national level, nearly reaching the historic peaks of cargo traffic volumes. Due to the advantageous geographical location, expected economic recovery and growth of larger Split region and higher demand, it is fundamental to provide overview of current cargo traffic indicators, trends and capacities and determine the development perspectives of Port of Split and cargo-related services, which should enable the increase of the port performance and recognition. The growth of the port cargo volumes, from the port performance standpoint and considering mainly wider local and regional significance of the port, is reachable solely with large investments in modernization of infra and supra structure, especially cargo-handling equipment, complementary to the demand for commodities and services of its hinterland.

Keywords: Port of Split, cargo traffic, port facilities, perspectives

1. INTRODUCTION

The paper deals with the problem of disregarded status of the cargo traffic activities in the Port of Split primarily based on the insufficient infrastructural investments, restraining the development possibilities provided by its favourable geostrategic location and promising hinterland, but also the inadequate position in the Croatian port and economic system. The overall business portfolio of the Port of Split can be divided into two types of activities, activities in international passenger and vehicle transport, including cruising, and transport in cabotage as a primary category and cargo traffic activities as a supporting activity. Nominated as a port of special international economic interest for the Republic of Croatia and classified as a Trans-European Transport Network (TEN-T) comprehensive port [1], the port is established mainly in passenger transport which exceeded 5 million mark in 2017, followed by 780,000 of transported vehicles [2]. Therefore, it is not surprising that the majority of investments in the last decade as well as the strategic goals of the competent Ministry were orientated towards development of passenger terminals and supporting facilities in the Port of Split, which were accompanied with the increased demand for services. These trends should be associated with the favourable development perspectives derived from the port location and importance of tourism for Croatian economy, having the share of 19,6% of its GDP [3], which surely had an impact on the passenger port development. The significance of the port in passenger transport activity is visible in its status in the overall market, where it is ranked first on the national level and in the Adriatic [4] while also having particular importance in Mediterranean, including cruise passenger traffic providing an incremental income in the last decade. The implications of the strategic orientation of the port had negative consequences on the degree of investment policy in the cargo terminals and supporting infrastructure, located in the northern suburb of the city of Split. Despite the low infrastructural modernization and lack of adequate cargo-handling equipment for the current level of cargo traffic, the port handled more than 3 million tons of cargo in 2017, reaching the cargo traffic levels of the Port of Ploče which had already performed the planned key investment cycles in both port and railway infrastructure [5]. As the competitiveness of the port is determined by the extent the cargo handled in port can reach its hinterland [6], the economic strength of the hinterland transport [7] and customer demand factor in the international trade [8], which are naturally located in the fundamental hinterland, the cargo traffic activities in the Port of Split, within the wider national port system, have mainly had regional freight port importance. As the value and strength of the interest market are one of indicators which determine the attractiveness of the port, it is necessary to analyse current and potential markets of the Port of Split to examine the demand of the interest region and provide the measures for possible expansion. In accordance with positive macroeconomic indicators in the Croatian and Split-Dalmatia economy [9] and taking into projection the current market and port hinterland demand, the aim of this research is to determine the development possibilities of the cargo traffic activities based on the current and historical trends, providing the overview of the projected demand for main commodities handled in the port and current port capacities. Complementary with the development perspectives, the requirements for the acquisition of essential cargo-handling equipment and contemporary, which would lower the operating costs and increase cargo handling efficiency, profit and reciprocally the overall throughput, and indispensable infrastructural investments are also part of the research problem.

2. CURRENT CARGO TRAFFIC IN PORT OF SPLIT

Cargo traffic activities in the Port of Split are located in the northern basins of the city, comprising Vranjic - Solin basin, where the main cargo port is located, three cargo basins in Kaštela area, Kaštela basin A, Kaštela basin B and Kaštela basin C, and dislocated Komiža basin for fishing needs. The whole port area is under jurisdiction of Split port authority and managed by individual concessionaires. These basins are equipped to accommodate different types of cargo, where general cargo terminal, along with terminal for bulk commodities and containerized cargo are located in the Vranjic - Solin basin, while terminal for liquid bulk cargo is located in Kaštela Basin C. Other basins are designated exclusively for the needs of supporting industry of cement, coal, slug and other output products intended for export, and in the following chapters will be only briefly described. There is also a significant and increasing cargo truck activity in the City port basin, along the quays of a passenger terminal, which are transported by ferries between Split and central Dalmatian islands contributing to total freight transport in the port.

2.1. Main road and rail connections to the cargo basins

Besides the access to the cargo terminals by sea, they are also reachable trough highway A1, State road D8, State road D1 and railway line intended for international cargo traffic M604, having also the optimal connection with 25 kilometres distant Split airport terminal in Resnik. The road modality predominates the overall cargo transhipment from the port providing the connection trough highway A1 to the Mediterranean corridor, a part of Trans European Transport Network (TEN-T), with capital Zagreb, an industrial node for Croatia, and Port of Rijeka but also the other outbound markets and metropolitan areas in Europe. The alternative to the highway A1 is the State road D8, a part of the European route E65, which extends from northern border crossing with Slovenia in Rupa to southern endpoint of the border with Montenegro in Karasovići. Also there is an access road State road D1 connecting Split with destinations in Dalmatinska zagora and land locked regions, representing its market.

The unfavourable spatial infrastructure of the rail network and inefficient and unreliable service determined the selection of the road as the transport service modality of the first choice in the port of Split, where only 10% of the overall cargo is transhipped (arrived and dispatched) by rail [11]. Trough extension of the railway connection intended for international cargo traffic M604 in the length of 323 km (Oštarije – Knin – Split), traditionally named Lička railroad, the Split port cargo terminals are connected to Mediterranean rail freight corridor RFC6 in Zagreb with main railway line Zagreb-Karlovac-Oštarije (M202) and other important metropolitan trade destinations in Europe. The main characteristics of the railway line M604are provided in Table 1.

Table 1 Specifications of the railway route Split – Knin – Oštarije

RAILWAY LINE NUMBER	RAILWAY ROUTE	LENGTH (km)	MAX. SPEED OF THE LINE	SPEED LIMITATION	ELECTRIFICATION	MAX. LENGTH OF THE TRAIN IN STATIONS	MAXIMUM ASCENT AND DECLINE	TRAIN BRAKING DISTANCE	PERMISSIBLE LOAD
M604	Oštarije – Knin – Split	323	65 to 100 km/h	20 to 95 km/h	NO	311 to 720 m	29 daN/t	700 m	20 t per axle

Source: HŽ Infrastructure, 2015 [12]

Paradoxically the permissible load on the main railway line M202 is 22.5 t/axle while the allowed load on the Oštarije – Split line is 20 t/axle [12], which creates cargo transport difficulties providing the maximum permissible tonnage of cargo and overall service efficiency of the transport of maximum possible amount of cargo. Also, it should be emphasized that the railway line M604 is not electrified opposite to the main line M202 [12]. The current capacity flow of the railway line from Split to Zagreb is 2*550 t/day of cargo transport [11]. As for the underdeveloped and poor state of the rail infrastructure, the overall capacity and throughput is questionable resulting with the significant decline in cargo turnover and narrowing the gravitational area of the port.

2.2. Terminal infrastructure and cargo – handling equipment description

The largest infrastructural surface for different cargo operations as cargo transport, transhipment, and storage is located in southern part of Vranjic - Solin basin, traditionally nominated as the North port [4]. It situated at the eastern part of Kaštela bay from cape Marjan in the direction 024° to the coast between Kaštel Sućurac and Kaštel Gomilica, covering the area of Kaštel Sućurac, Solin basin, Vranjic basin and Split shipyard basin at Supaval [10]. The southern area is administered by a primary concessionaire Luka d.d, having the cargo vessel and freight manipulation as a primary activity, while the northern part of the basin under the silos for bulk commodities is administered by Ameropa žitni terminal d.o.o company. The whole basin possesses 1,854 km of operational docks, eight berths with maximum draft of 10.3 meters (figure 1.). However, Split port authority invested in the dredging process of the seabed throughout the whole terminal which was finished in the second half of 2018, providing the maximum depth of 11.0 meters which allows to accommodate ships up to 40,000 dwt, with the exception that there are areas where the depth is higher than the official one. The northern surface of Vranjic – Solin basin has total length of approximately 710 m with depths from 4.7 m to 10 m, while the southern surface has total length of about 920 m with depths varying from 6.5 m to 10.3 meters [13]. Along the southern surface, bulk and general cargo terminals are located having the length of the surface of 550 m^2 while the whole area possesses five berths, intended for various types of cargo transhipment. These terminals have 10,000 m^2 of open and 11,600 m^2 closed background storage spaces [14]. In the bottom of the southern surface, berth number 5 is equipped with RO-RO ramp having the maximum draft of 7.2 meters. Under the Silos surface in the northern part, having a ground level warehouse and silos with the total capacity of approximately 70,000 metric tons [15], the berth number 6 is intended for loading and unloading of grain commodity. The length of the surface is 210 meters, having a draft along the coastline of 8.6 meters but with the use of spacers it is possible to berth vessels with maximum draft of 10 meters. The other two berths 7 and 8 are located at Obala Vranjic with the overall length of 500 meters and allowed draft along the coast up to 7.3 meters, having miscellaneous intended use [13].

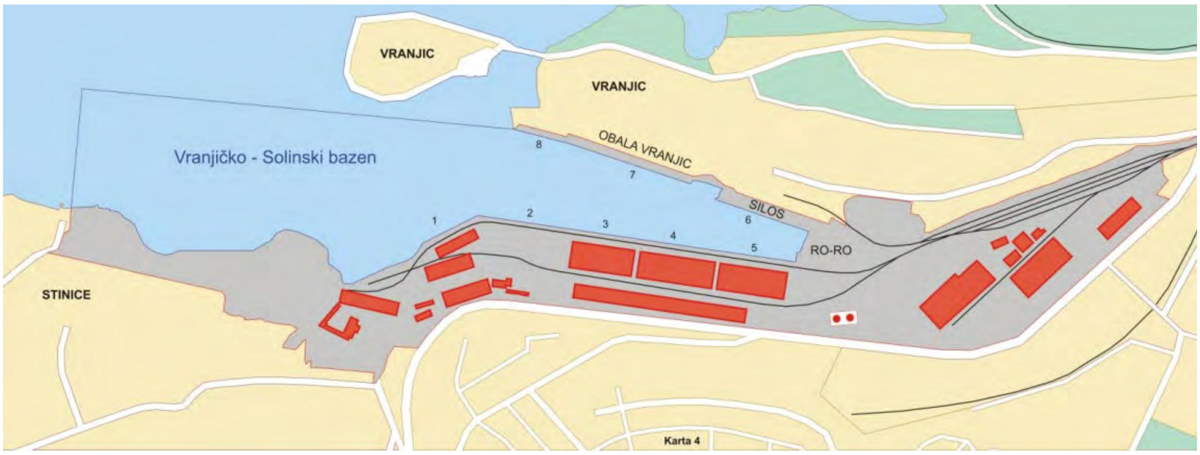


Figure 1 Vranjic - Solin basin

Source: Port Authority Split, 2018 [16]

The container terminal is located in the south-eastern part of the basin behind the RO-RO terminal, having combined surface of about 20,000 m^2 and annual capacity of 30,000 TEU, with direct connection of two railway tracks and a road that brings cargo directly to the ships[4]. The road and rail networks are stretching thorough the entire port, enabling the provision of intermodal services. The road modality is burdened with infrastructural restrictions as there is no direct connection of the port with highway A1 and with two access roads, Solinska road on the eastern part of the port and Put Sjeverne luke road on the western part having limited throughput. Also, as for the omissions in strategic infrastructural planning in the city of Split visible in the transhipment of cargo from the port to gravitational area inland like the height of tunnels, overpasses and width of the roads the competitiveness of the Split port decreases in comparison with the other central Dalmatian ports, especially Port of Zadar. There are seven railway tracks in the land part of Vranjic – Solin basin, having permissible load per axle of 20 t or 8 t/m. The speed limit on the tracks is 5 km/h while the maximum allowed length of the composition to the track is 30 wagons [17]. Also, in the south-western part of the port the truck parking space is located with the size of 10,000 m^2. Some of the main specifications of the Vranjic – Solin basin are shown in Table 2.

Table 2 Specifications of the Vranjic – Solin basin

Size of the yard (m^2)	198,027	
Open storage area (m^2)	80,000	
Closed storage area		
along the operational docks (m^2)	22,400	
in the background (m^2)	11,400	
Covered (roofed) storage area (m^2)	6,000	
Refrigerated storage area	Size (m^2)	Volume (m^3)
in the cargo port	3,300	15,300
for fruit (in the cargo port)	2,000	/
Grain terminal with silos	Volume (m^3)	Metric tons (MT)
old silos-cells	20,837	16,250
new silos	28,000	21,840
floor storage area	25,000	20,000

Source: University of Split, 2017; Vukić, Ukić Boljat, Slišković, 2018 – modified; Luka d.d. Split, 2018

The other cargo terminals are located north of the city of Split in the nearby Kaštela area comprising Kaštela basin A, Kaštela basin B and Kaštela basin C. The basins have the possibility of primarily direct road connections to the terminal while terminals in Kaštela basins B and C also possess rail infrastructure extending directly to the terminals and quays which increases efficiency of the service and provides the service of intermodal transport. One of the disadvantages of these terminals is problematic of the capacity on the state road section D8 Trogir – Split – Omiš which is considerably below the traffic needs. The main specifications of Kaštela basins are shown in Table 3.

Table 3 Specifications of Kaštela basins

	Quays	Berths		Berth Length	Maximum draft
Kaštela basin A		Sustipan berth		80 m	8.5 m
Kaštela basin B		Berth 1	loading and unloading of liquefied gas cargo	80 m	9.7 m
	Sv. Juraj I	Berth 2	loading processes of cement and cement products and slag unloading for complementary industry located on the shore	200 m	8.2 m in the western part (with the use of spacers)
		Berth 3		75 m	
	Sv. Juraj II	Berth 4	coal unloading	160 m	6.6 m
		Berth 5	Tanker truck loading and unloading with fuel and gas commodity for the purpose of supply of islands	40 m (Ro-Ro ramp)	2.5 m along the ramp
Kaštela basin C	Sv. Kajo	Berth 1	loading operations of cement and cement products and unloading of slag.	219 m	8.2 m (with the use of spacers)
	INA tanker terminal	Berth 1	Bunkering operations by shore to ship fuel transfer	150 m	11.3 m
		Berth 2			
		Berth 3 (Mala obala Solin)	Berthing of smaller tanker vessels	103 m	6 m
	Brižine	Berth 1	berthing ships in lay-up (out of service), ships carrying out deratization and other needs		
		Berth 2	berthing of fishing and other vessels	70 m	
		Berth 3		50 m	
		Berth 4	exclusively for unloading fish and loading of fishing gear and supplies	70 m	

Source: Port Authority Split, 2018 [13]

The Komiža basin is dislocated basin on the island of Vis having the main purpose of provision of fishing services.

Cargo – handling equipment is one of the essential structural element in the production of the overall port service. The degree of technological development, type, capacity and performance of individual mechanization unit is specific for each port, its size and purpose, trying to endeavour the balance between CAPEX and OPEX on one side and projected profitability of the service and capacity utilization on the other. The main cargo – handling equipment in the southern part of the Vranjic – Solin basin are three types of cranes intended for the usage on the different terminals as follows:

- one mobile harbour crane type Liebherr with the capacity of 104 tons on the container terminal,
- one mobile harbour crane type Sennebogen 870 with special grab and three portal cranes type Ganz with the capacity of 5 tons on the terminal for bulk cargo.

It should be noted that as for the lack of adequate equipment the mobile harbour crane type Liebherr is used for manipulation of bulk cargo when available. The other port equipment in the container terminal include one container forklift with capacity of 44 t, one reach stacker with capacity of 40 t, one forklift with capacity of 22 t, two container trailers, one container truck and one terminal tractor for container trailer. The remaining mechanization relates to numerous forklifts, tractors, skid and wheel loaders and others. On the northern part of the basin where the terminal for agriculture commodities is situated, the port mechanization is related with handling of bulk commodities like loading cranes, transport systems - conveyors / elevators, loaders, conveyor belts and other relevant equipment [4]. The other basins are equipped with cargo – handling equipment related to the individual business orientation of the industrial production and type of the cargo handled, like crane structures, loading arms, ship unloaders, conveyor system and associated metering points for the purpose of unloading coal and other raw materials in cement production or system of pumps, pipelines and storage tanks for liquid bulk cargo handling on tanker and gas terminals.

2.3. Intermodal terminals

The intermodal transport chain in the Split port consists of container transport from and to the primarily southern part of the Vranjic – Solin basin where the container terminal is situated. As previously mentioned, approximately 10% of the cargo loaded or unloaded at the cargo terminals are transported by rail, while the majority is transported by road. These constellations are worrying especially when comparing it with the average values of railway transport participation in the shipping of containers from Croatian ports in amount of 25% and other competitive ports in the external environment [18]. Intermodal transport chain values for three major Croatian cargo ports are provided in Figure 2.

Figure 2 Share of rail and road transport in intermodal service of cargo delivered and dispatched for three major Croatian cargo ports in 2015

Source: CBS, 2015 [19]

Intermodal service in Vranjic – Solin basin has the capability of direct cargo transhipment from vessels to the rail wagons, as the railway tracks have direct access to the terminal extending from the marshalling yard located in the eastern part of the basin's land area. Also the predomination of the road infrastructure enabled the intermodal transport service combining maritime and road modalities, with cargo delivery on container terminal through Solinska road on the eastern part of the port or trough Put Sjeverne luke road on the western part of the port where bulk and general cargo terminals are located, and vice versa. It is also important to emphasize the possibility of road and rail intermodal cargo transhipment and vice versa. Vranjic – Solin intermodal nodes are shown in Figure 3.

Figure 3 Vranjic – Solin basin intermodal nodes

Source: Created by authors

2.4. Freight statistics in the Port of Split

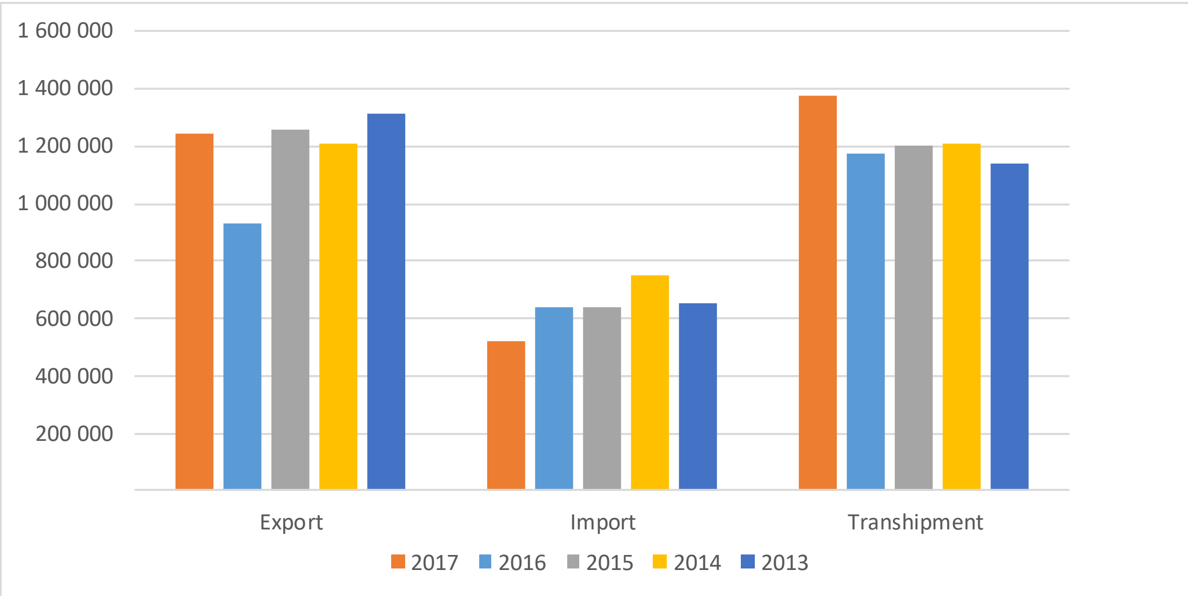
Despite the low investment activity in the port infrastructure, storage spaces and cargo – handling equipment, the cargo basins reached the annual turnover of 3,1 million tons of cargo in 2017 representing a 12,5% of increase related to the previous year recorded by 2,107 vessels calling to the cargo basins [20]. It should be noted that the statistics comprises all individual traffic of relevant stakeholders in the port area. Table 4 provides the inside of freight traffic statistics in a five year period divided on the main concessionaires on the operative quays providing industry activities, where the overall traffic almost reached historical peaks recorded in 2014. It is evident that the majority of concessionaires recorded an increased traffic on the respective operational quays while only traffic of agriculture commodities on Žitni terminal suffered a 35,5% of decrease.

Table 4 Freight traffic statistics in the Port of Split for period of 2013 – 2017

	2013	2014	2015	2016	2017
Luka Split	319,862	311,666	294,808	351,339	380,125
INA – tanker terminal	403,271	453,100	426,646	355,164	435,170
Žitni terminal – Silos	267,828	316,460	365,198	316,613	207,477
Cemex	1,249,701	1,217,676	1,120,082	753,108	983,535
Others (Salonit, INA b, trucks)	867,585	867,551	895,574	968,562	1,130,040
OVERALL	3,108,247	3,166,453	3,102,308	2,744,786	3,136,347

Source: Port Authority Split, 2013 – 2017 [20]

More than 50% of the total cargo traffic in 2017 referred to bulk cargoes, 35% were general cargoes and the rest were liquid cargoes. One of the important business characteristics of the cargo flows calling the Port of Split is the ratio between exported and imported cargo, where the port exported 40% of the overall cargo and imported only 17%, while the majority (53%) was transhipped in 2017 (Graph 1.) [21]. This ascertainment defines the significance, purpose and position of the port in the overall port system, defying its regional character having moderate demand from its gravitational area with a strong transit activity and significant freight export.



Graph 1 Port traffic statistics related to freight export, import and transhipment in period from 2013 – 2017

Source: Port Authority Split, 2014-2018

The main activities of the cargo port are transport and transhipment of diverse commodities, mostly dry bulk products like iron ore, coal, cement and grain for key regular clients in the direct hinterland, with various seasonal commodities like sugar, salt, fertilizer and others depending on the demand. Also, there is a high demand in quartzite and slag for industries in Bosnia and Herzegovina. CEMEX factories export 70% of production, supplying countries such as Libya, Malta, Israel, Egypt, Algeria, Italy and others. The key general cargo commodities are metal products and wood. Transport of yachts and small vessels especially in the summer periods and special cargo like wind turbines intended for projects in the port hinterland should also be emphasized. The cargo terminal in Kaštela basin C is also a centre for import and distribution of petroleum products for INA concessionaire, intended to supply the regional economy with oil derivatives. Transport of containers recorded a continuous increase in recent years as well as the truck cargo transport between Split and central Dalmatian islands. The segmentation of cargo by type in overall port traffic in the cargo terminals are provided in Table 5.

Table 5 Cargo traffic segmentation by type in the cargo terminals in period 2014 – 2017

TYPE OF CARGO	2014.	2015.	2016.	2017.
Coal, petroleum coke	156,667	147,099	137,628	146,434
Oil and derivate	463,793	435,685	364,982	444,028
Bananas	25,928	8,804		
Salt	31,260	57,530	33,550	23,400
Metallurgy products	14,993	/	/	/
Iron	55,278	27,385	39,904	46,328
Cement	503,908	387,556	242,006	385,696
Bagged cement	/	34,995	13,516	/
Iron silicates	2,997	/	/	/
Sugar	48,890	63,474	31,171	12,061
Lime	5,592	5,292	2,825	1,513
Cement clinker	344,553	374,081	215,409	345,252
Stone (in bulk)	3,340	10,522	26,001	158,550
Asphalt	3,409	1,328	706	1,198
Pebble	/	/	/	11,010
Cinder	225,438	201,760	232,685	231,164
Containers	82,636	90,298	100,571	115,624
Chemical fertilizers	/	/	33,000	/
Grain	330,460	366,700	316,613	220,186
Water	340	/	/	220
Explosives	/	1,038	1,179	1,209
Timber	/	3,442	1,629	10,053
Other goods	866,971	885,319	951,411	982,421
TOTAL	3,166,453	3,102,308	2,744,786	3,136,347

Source: Port Authority Split, 2014-2018

It is evident in Table 5 that container transport in the Port of Split remained one of the few cargo segments which recorded a steady increase throughout the years having minor oscillations, where 11,207 TEU was transported in 2017. The overall container transport from 2014 to 2017 is shown in Table 6.

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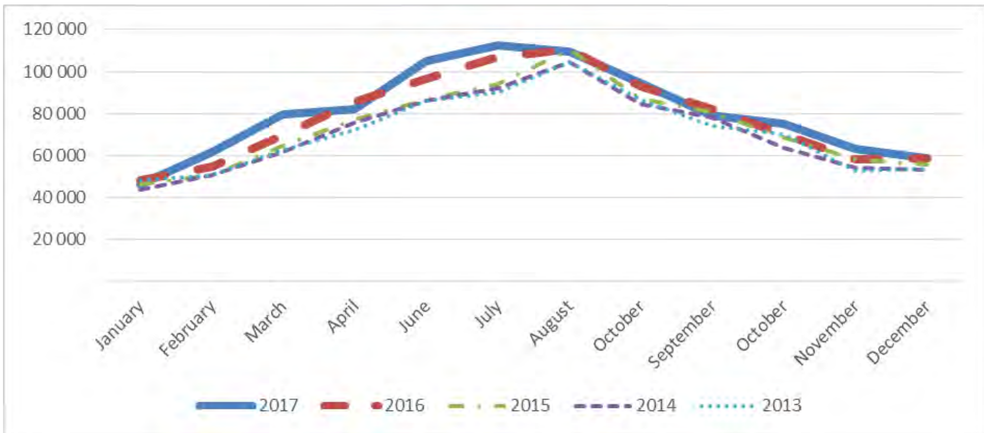
Table 6 Container traffic indicators from 2014 to 2017

YEAR	2013.	2014.	2015.	2016.	2017.
TEU (loaded and discharged)	5,062	9,476	9,240	9,977	11,207

Source: Luka d.d. Split, 2018

The container traffic flows in the port of Split are mainly operated on the basis of regular weekly feeder service, connecting the cargo port with hub terminals in the Mediterranean. Starting in the year 2017, Maersk and CMA CGM jointly operate on the weekly container service, by chartering the cargo space on the X-PRESS Container line, Adriatic X-PRESS 1 (ADX 1), an XPRESS Feeder service route directly connecting the port of Split with Freeport container terminal in Malta. The overall feeder container traffic flow service has three vessels in a fleet, 11 port of calls and weekly frequency with overall duration of 21 days. There are two container lines on the Adriatic X-PRESS 1 (ADX 1) service route, northern and southern route, of which the north service (the orange line on figure 14.) comprises five (5) port of calls along with the origin and destination port in Malta. The feeder line traffic flow is as follows: Freeport (Malta) – Bar (Montenegro) – Ancona (Italy) – Ravenna (Italy) – Split (Croatia) – Ploče (Croatia) – Freeport (Malta) [22]. The main markets for transport of containers is China, having the largest share in both cargo import and export, having also steady container flows directed to the remaining countries of the Far East and countries of the Arabian Peninsula and Middle East.

Besides containers it is important to indicate the increasing transport flow of trucks, transported between Split and Dalmatian islands which amounted to 181,000 units carrying around 967,000 tons of cargo, of which 96% of units referred to local traffic carrying 90% of the overall truck cargo flow in 2017 [20]. The breakdown of amount of cargo transport on trucks per month in period from 2013 - 2017 is provided in Graph 2. The graph indicates the increase in truck traffic with no significant oscillations over the analysed period.

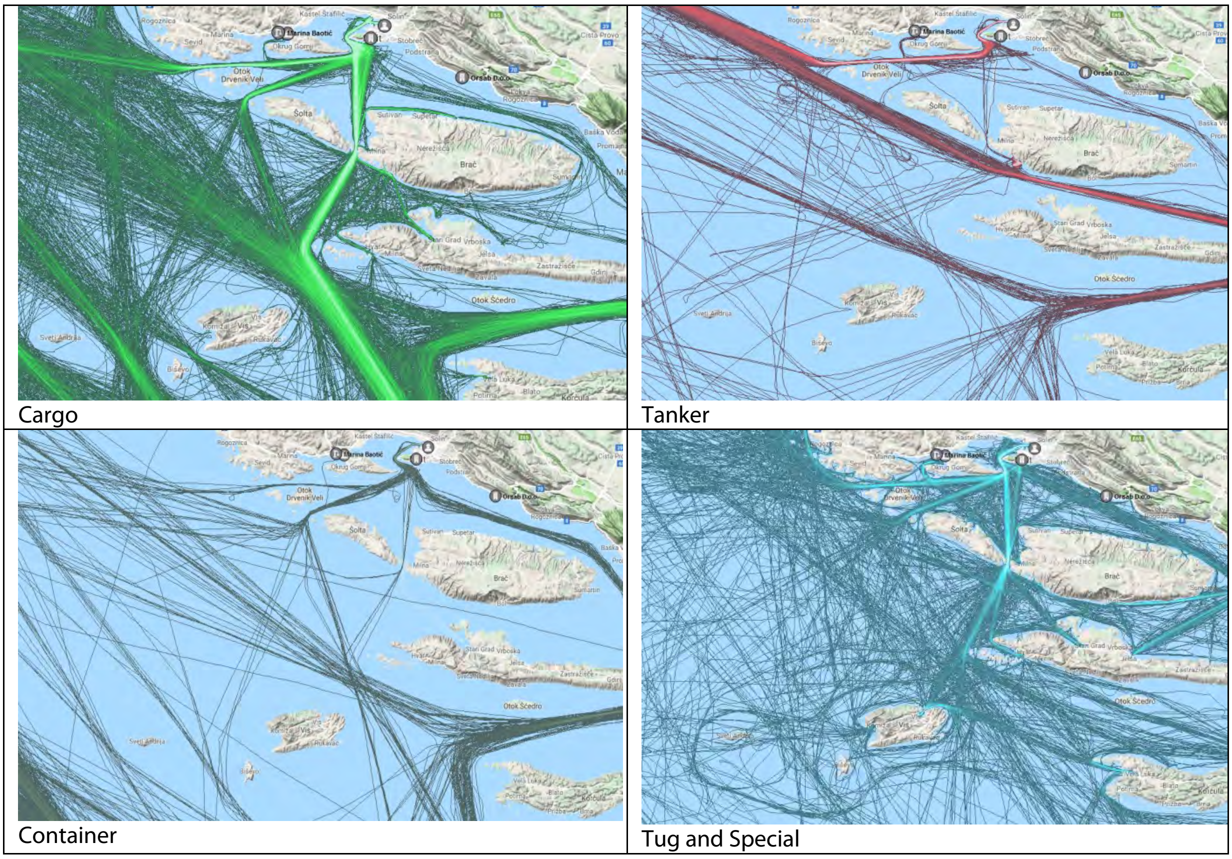


Graph 2 Port of Split, Cargo on trucks per month, 2013-2017

Source: Port Authority Split, 2014-2018

2.5. Current markets in the cargo activity of the Port of Split

The current markets of the Port Split are divided according to the business portfolio of the containing passenger and vehicle traffic and cargo traffic as the main business activities. While the main markets regarding the transport of passengers and vehicles (trucks, buses, private cars) are central and south Dalmatian islands with few destinations along the coast, as well as the international market of passenger and vehicle transport with Italy, the most prominent markets in the segment of cargo transport are located in northwest Bosnia and Herzegovina, with accompanying destinations in Croatia, mainly in Split-Dalmatia County which represents its hinterland [23]. Imported cargo is primarily intended for local markets of various industries in port hinterland, but also by supplying the steel industry in Bosnia and Herzegovina. In addition, various goods are exported to the Middle East, including wooden products. General cargo terminals are used to provide trade services to worldwide destinations depending on the demand for commodities, while the container terminal is connected with Mediterranean hub ports predominantly in the Adriatic. According to the AIS (automatic identification system) data regarding the density of traffic, it is possible to determine the direction of the main maritime cargo traffic flows calling the cargo terminals of the Split port, divided on four categories of cargo ship types, cargo vessels mainly related to Handysize ship type, tanker vessels (Handysize), container vessels (feeder vessels) and tug and special crafts (Figure 4.)



Source: Marine Traffic, 2017

Figure 4 Density of sea traffic at the entrance to the Port of Split (AIS data, 2017)

In accordance with known facts and data in Figure 4, it is evident the strong dependence of container and tanker cargo traffic in Port of Split on the regular feeder service on one side and consolidated tanker traffic market flows on the other, with smaller oscillations. These tanker traffic flows and trade of liquid cargo are primarily intended for distribution of oil and petroleum products of INA company along the northern Croatian coast using smaller vessels, with occasional port of calls of larger tanker vessels, which is visible from the usage of Drvenik channel as the main access to the port, with limited utilization of Brač channel and passage Splitska vrata which are normally used when navigating from south through Otrantska vrata. It should be emphasized that the pilot station for vessels carrying dangerous cargo is also located at the entrance to the Drvenik channel. The container flows show strong dependence on feeder services with smaller deviations, while the density of tug and special vessels traffic flows are dispersed and strongly depend on the main market principles, mostly from the demand factor. The first category of cargo vessels are mainly related to general cargo ships and bulk carriers type Handysize, where the origin and final destinations are determined based on the ports industrial activity in the gravitational area and demand in receptive markets.

3. IMPLICATIONS FROM THE EXTERNAL ENVIRONMENT DETERMINING THE FUTURE DEVELOPMENT OF THE CARGO TERMINALS

3.1. Regulations determining the vision of the cargo terminals

The future development of the cargo terminals in the Port of Split is determined primarily by the level of demand for its services, strength of industrial activity in the gravitational area and hinterland, level of competitiveness with rival ports, range in infra and supra structure investment and modernization, but one of the most important development indicators is the economic interest and strategic orientation of the State based on the individual port growth perspectives. The potential of the Port of Split for the development in the freight segment was confirmed with the adoption of the Transport Development Strategy of the Republic of Croatia (2017 – 2030) in 2017, indicating the appropriate cargo specialization and proper development of the railway freight infrastructure as the development measures. However, the Strategy prescribes development of the Port of Split mainly in passenger and cruise transport, having favourable implications on the potential future growth of the port by creating multiplicative effect on the whole region especially important for the sustainable development of the islands, as an important segment for Croatia [25]. Within the National Development Plan of ports of economic interest of special (international) economic interest for the Republic of Croatia, the State provided the measures for sustainable development and guidelines to achieve competitive advantage of Croatian ports in the wider port system. According to the Development Plan, the Port of Split should maintain its function as important regional freight port for the development in cargo traffic while emphasizing the importance of development primarily in passenger and cruise transport in the national port system [23]. Both regulations indicate the subsidiary activity of the freight transport in the Port of Split which is logically due to the importance of international and national passenger transport, but the investment levels and proposed development goals in the segment of cargo traffic is below the current freight traffic values. The Port of Split reached the levels of cargo turnover of Port of Ploče in both 2016 and 2017 without major investments, compared to the Ploče port, indicating the potentials and necessary modernization of the needed resources or Port of Zadar. The proposed goals for the cargo traffic development are determined for the main cargo categories such as containers, general, dry bulk and liquid cargo with cargo trucks in the trade with islands, based on the current levels of the individual cargo traffic. The anticipated full potential growth is predicted only in the container transport regarding the recorded increase in the last decade, while the potential increase in the rest of the cargo categories is marked as moderate. The objectives of the port of Split for different types of cargo traffic are shown in Table 7.

Table 7 Objectives of the port of Split for different types of cargo traffic

TRAFFIC SEGMENT	CURRENT ACTIVITY IN PORT?	POTENTIAL GROWTH 2030.	GOAL	LOCATION IN PORT	HOW?
CARGO TRAFFIC					
Containers	+	+	continue to operate as a regional container port and serve the immediate Split area and the local regional hinterland	Vranjic – Solin basin	Possible growth of container business should be realized: - Further containerization of the export of marble and wood. - Formalization of the current storage space for containers, which will facilitate the possible use of additional equipment.
General cargo	+	+ / -	continue to act as the export port for regional production of metal products and wood serve as an import port for project cargo	Vranjic – Solin basin	Possible business growth with respect to the general burden can be achieved by the following activities: - Revitalization of Bosnian metallurgical production. - Revitalization of steelworks in Split and the use of new production technologies. - Increasing the export of wood. - As a result of the expected growth of local steel production, a reduction in exports of metal waste is expected.
Dry bulk cargo	+	+ / -	seasonal traffic (sugar, salt, fertilizer, etc.) continue to play an important role in the handling of coal, petroleum coke, cement and grain for key permanent customers in the immediate hinterland concessionaire intends to handle the quartzite and slag for the company ElektrobosnaJajce	Vranjic – Solin basin (for seasonal traffic flows, quartzite and slag) berths of the concessionaires (cement and grain cargo)	handling coal, quartzite and slag for the company ElektrobosnaJajce will depend on the ambition of concessionaires the concessionaire will retain the current position as regards seasonal traffic flows, which are linked directly to the port's hinterland.
Liquid cargo	+	+ / -	continue to serve as a centre for the import and distribution of petroleum products for INA	the current location of the INA facility	INA will continue with current activities, i.e. supplying the regional economy with oil derivatives.
Other	+	+ / -	continue to handle substantial amounts of loaded trucks transporting goods to the islands	part of the ferry operations will be transferred to the pier that will be built in the Stinice area. the rest of the truck transport will be handled in the city basin.	The potential growth of truck traffic will be enabled: - Construction of a new pier in Stinice - Expanding Sv. Petar pier and quay of knez Domagoj

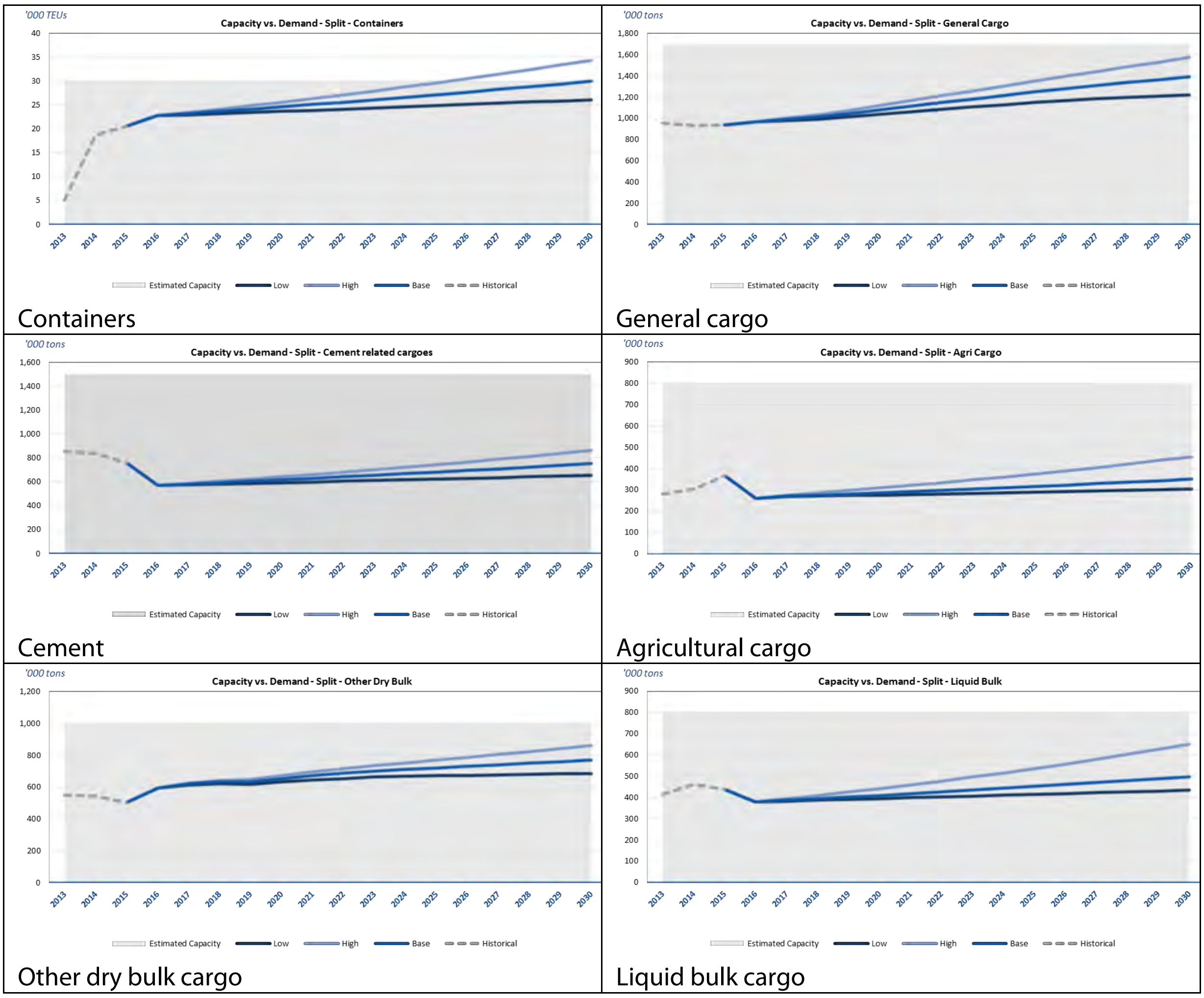
Source: MTBS, 2016

Infrastructural projects for the modernization of the cargo terminals, presupposed in document are related to the construction of a new operational surface in dislocated northern area of Stinice, located in the Vranjic – Solin basin for the purpose of transferring the domestic and international truck transport from the

City port basin. The project foresees the reconstruction and construction of new port infrastructure on the Split port area, mainly the investment in construction of berths for Ro-Ro vessels. With the potential project implementation, there would be a significant change in the structure and density of maritime traffic for the northern basins of the port of Split, Kaštela and Vranjic – Solin basins. Also, there is intention from the Port Authority Split for the reconstruction and extension of the port infrastructure of Kaštela Basin "A" and reconstruction of INA oil terminal infrastructure in Kaštela basin "C" [23].

3.2. Projected demand for individual cargo type in comparison with current port capacities

Analysis of the port capacity was taken from National Development Plan of ports of economic interest of special (international) economic interest for the Republic of Croatia, where the projected cargo traffic of the main cargo categories in the Port of Split based on the base, low and high scenarios were compared with current and planned infrastructural capacities on related terminals. Base scenario assumed an increase of 2,0% per year, in accordance with the expected growth of Split region for all types of cargo except cement where with the expected growth was based on the increase in overall Croatian economy. The increase in cargo traffic in the minimum scenario was set to 1,0%, while the maximum scenario varied form 3,0% to 4,0% depending on the projected industrial activity of concessionaries and estimated demand. The projection of capacities and demand for individual commodities is shown in Figure 5.



Source: MTBS, 2016

Figure 5 Capacity in relation to the demand for certain cargo type in Port of Split

According to the data provided in Figure 5 it can be concluded that the current infrastructural capacities are sufficient for the projected demand for almost all cargo type, except for the container storage capacities, having an annual capacity of 30,000 TEU, in the maximum demand scenario. There are three solutions for the maximum scenario in long term projection if the capacities become insufficient: the storage capacities of the existing container storage area will need to increase, the storage time of containers will need to decrease or the working hours for container traffic activities should increase from 14 to 24 hours per day in order to increase the container reception capacity. The combined capacities of cement factories in Split in yearly amount of approximately 1,5 million tons, facility with silos and unloading equipment for agricultural bulk cargo having yearly capacity of 800,000 tons as well as terminals for general, liquid and other bulk cargo should remain sufficient in all scenarios [23].

3.3. Geopolitical struggles in the revitalization of Unska railroad

Unska railroad is an essential resource in the projected development, not only for Port of Split but for all central Dalmatian ports, as it represents the shortest distance towards metropolitan area of Zagreb and markets situated in Central and Eastern Europe. This 177,9 km long railway connected city of Knin on the Croatian part with Novi Grad (Bosanski Novi) in Bosnia and Herzegovina [26], but mostly as for the unfavourable geopolitical relations between countries and various political decisions it is still inactive with devastated infrastructure. The revitalization of the railroad would represent a significant perspective and with the trade agreements of various resources could become the driver of economic development for both countries and respective ports. This would raise the competitiveness of Port of Split in the expansion to the new markets in port hinterland as for the shorter distances and transport costs, and enable the connection to the Mediterranean and Rhine – Danube corridor [4]. The shorter distances in rail but also maritime traffic in delivery of goods to the cargo terminals of land-locked countries and especially European Commission's policy and tendency of redirecting goods traffic from road to rail freight modality [27] should increase the throughput in Port of Split creating the competitive advantages and unfolding the markets primarily in northern Croatian regions, as Posavina and Slavonia, rest of Bosnia and Herzegovina as well as the new market in Serbia, more accurately in the autonomous province of Vojvodina [28]. It should be emphasized that the Unska railroad was completely electrified [4], while some parts of the rail tracks in Bosnia and Herzegovina were renewed and electrified in 2018 [29]. Also, with the planned reconstruction of the railroad, the port would strengthen the quality of intermodal services by investment in the road, rail and port cargo terminal capacities. Considering the estimated traffic on the mentioned railroad of yearly 4 million tons of cargo and 1,5 million passengers in the past periods [30], the part of that cargo would be redirected to port of Split and would affirm the potential and the need in infrastructural development of the cargo port area. The area of Bosnia and Herzegovina disposes with numerous natural resources and minerals such as gypsum, bituminous coal, quartz, bauxite and manganese, which could, with the direct connection to central Dalmatian ports, be more efficiently dispatched and significantly increase the cargo traffic of respective ports. As for the mentioned reasons, the interest of Chinese investors as a majority owner of the Port of Zadar for reconstruction and modernization of Unska railroad is not unexpected [30].

3.4. Trends in economy of Croatia and Split – Dalmatia County as development indicators

Gross domestic product (GDP) as the value of all produced goods and services provides inside of economic strength of observed regions, and in the European Union, the economic development of regions in the is measured with GDP per capita (Purchasing Power Standards - PPS) as a percentage of the EU average. This indicator shows how much a region is more or less developed than the average EU development measured by GDP per capita in PPS.

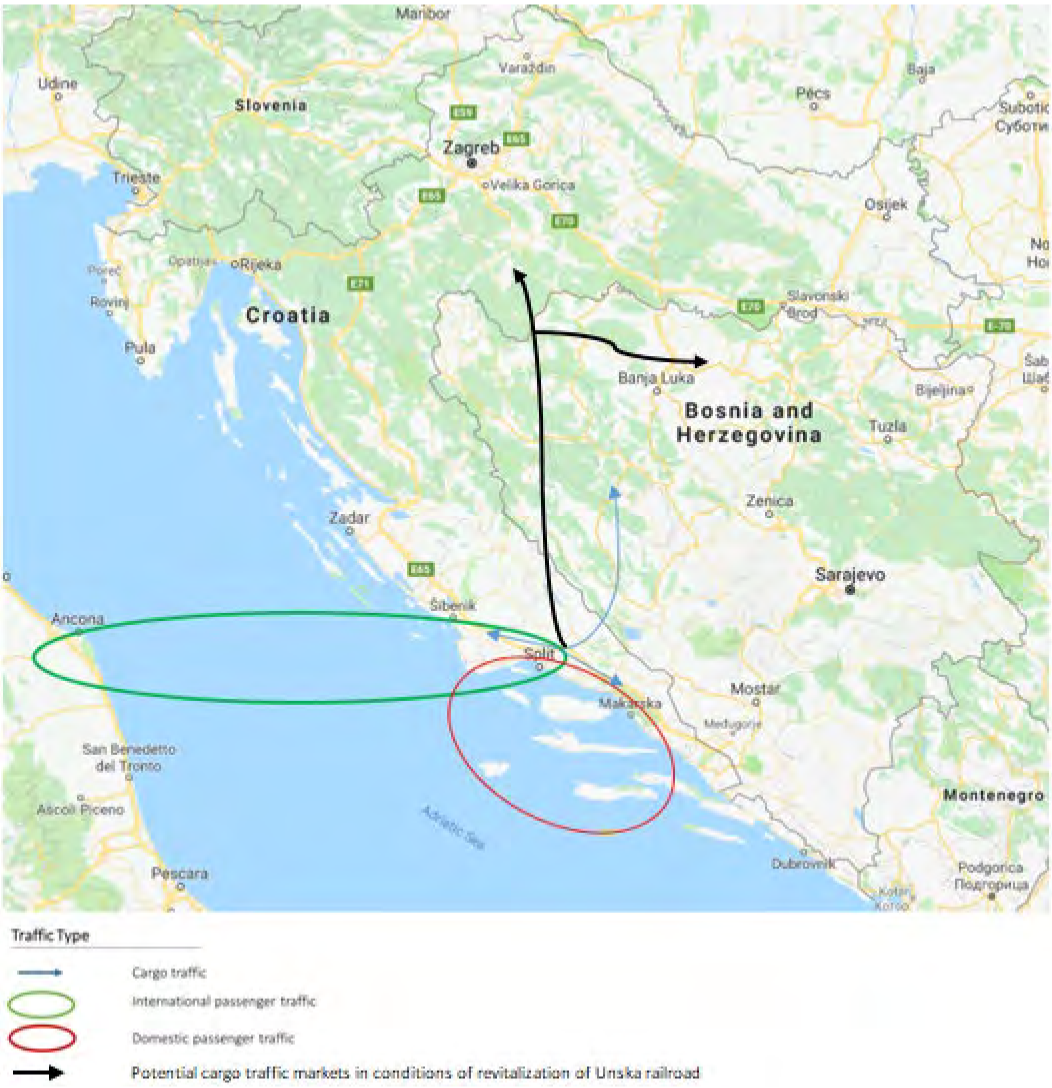
Based on the recent research from Croatian Chamber of Commerce, GDP on national level increased in 2015 by 2,4% in comparison with previous year, representing the fastest dynamics of nominal growth since 2008. Moreover, in 2015 a negative trend of real GDP growth has been interrupted, which has been ongoing since 2009, as a result of favourable trends in personal spending and investment, while exports of goods and services only continued a positive trend started in 2013. The nominal GDP growth was recorded in all Counties in 2015, but still below the trends in 2008 as an influence of global economic crisis. GDP of Split – Dalmatia County increased on average of 1% in 2015 in all categories compared to the previous year, continuing the positive recovery form the recession period after the year 2008 [31]. In 2019, the European Commission increased the estimate of Croatia's GDP growth to 3,1 % [32] affirming the development perspectives. Change rates of industrial production in Croatia recorded an increase of 1,9% in 2017 and slight decrease in 2018 in amount of 1%, with positive long term outcomes in following period [33]. All the above mentioned positive indicators on national and regional level are important not only for projection of dynamics of overall Croatian economy, but also for the value and projected industrial activity of hinterland of the Port of Split, representing the exclusive market for the port and defying the future demand for its services and complementary the level of attractiveness. Also the positive trends in economy of Bosnia and Herzegovina, visible in the GDP growth of 3,3% [34] and 3,6% [35] increase in industrial production in 2017, are encouraging indicators for prosperity of production and consequently the import and export activities which should also affect the traffic route towards Port of Split and the overall demand for services and traffic.

4. MODERNIZATION OF MARITIME AND RAIL FREIGHT TRANSPORT IN SPLIT AS AN INVESTMENT FOR LONG-TERM DEVELOPMENT

When analysing port competitiveness it is necessary to determine the possible general inputs affecting its position in the overall port system, as geographical location, port infrastructure, and hinterland transportation [36] but also the State's vision of individual port perspective which is determined by level of investments in the whole supply chain. These inputs further decompose on factors related to decision makers of the supply chain and port users in the selection of the port like costs, efficiency of cargo – handling equipment and other means of transport, port congestion, quality of services, port hinterland distances, frequency of vessels port calls, availability of port capacities and others [36].

The Port of Split has favourable geostrategic location situated in the central part of the eastern coast of the Adriatic basin, which enabled the development of both maritime passenger and cargo transport. Regardless of the regional importance and markets mainly intended for the local industries in the port hinterland, the cargo terminals achieved respectable business result of port traffic amounts in the last few years, positioning itself as an important entity in the national port system. These constellations confirm the potentials of the port and interest strength of the hinterland and users. Demand for services of the Port of Split is dispersed to numerous entities without exclusivity for supply of strategic partner like in numerous other ports which can be a business risk in negative economic environment and circumstances, which it can only be stimulant for further business development. The development possibilities are influenced by constraining factor in form of regulations determining the future development of the freight transport in port Split, as inadequate development measures of cargo terminals in achieving its full potential, mainly as for the lack of infra and supra structure investments, modernization and connectivity. As for the deficiency in strategic infrastructural planning of road modality, bottlenecks on the access roads to the Vranjic – Solin basin emerge, affecting the competitiveness of the Split traffic route in the transport of special cargo like wind turbines intended for projects in the port hinterland or heavy cargo having large size but also high values. These bottlenecks are located on the crossroads of the Solinska road and Domovinskog rata road having the direction towards east of city of Split, in the form of limited space for truck to perform left turn when loaded with cargo. The second is located at the end of Domovinskog rata road passing below viaduct of Zbora narodne garde road having lower heights than required for the transport of these special cargoes. In continuation of the Zbora narodne garde at the first exit in the roundabout, the truck loaded with cargo has limited space to perform the right turn, preventing the access to the state road D1 and furthermore to highway A1. Also on the state road D1 there are numerous tunnels having insufficient heights especially for cargoes whose dimensions are increasing with the development of technology. Moreover, the access roads in the Vranjic – Solin basin have limited width and throughput as well as the exit roads form Kaštela basins. These adversities are affecting the efficient cargo delivery to the interested parties, thus decreasing the possibility of selection of Split port as node in an overall supply chain and maximising profit.

Strategic element of port development in economic and competitive terms is the level of rail and port connectivity [37]. The railway running towards cargo terminals is burdened with continuous problems of maintenance and delays, decreasing the efficiency of the supply chain and increasing costs [4]. Without modernization and investment in rail infrastructure, the cargo port in incapable of achieving competitiveness in the region. It is manifested trough uncertainty in on time delivery of goods and cargo which proportionally leads to increase in the total cost of transport but also insufficient safety measures of signalization equipment. One of the fundamental obstacles in the further development of the Split cargo terminals are the technical limitations in acceptance and manipulation of cargo. Modernization of the railway is imposed as a need but also an obligation as it is fundamental for the integration of the port in the intermodal transport chain [4]. Revitalization of Unska railroad imposes as vital for prosperity and affirmation of port Split and Split traffic route. It is estimated that the overall cargo traffic of raw materials between countries on this route would vary between 500,000 tons and 1,000,000 tons [30], of which significant amount of cargo would be redirected to the Split cargo terminals due to the large storage capacities and large depths. Also, with the mentioned railway reconstruction the freight traffic of Port of Split becomes competitive for markets in the narrower area of Eastern Europe. The current and projected markets of the freight traffic of Port of Split are shown in Figure 6.



Source: MTBS, 2016 – modified

Figure 6 Current and projected markets of Port of Split

The analysis of port capacities related to the long – term projected demand provided two important implications. Firstly, the current port infrastructural capacities are sufficient in the maximum projected scenario of the port traffic growth, while secondly the projected demand in all scenarios indicate increase of demand for observed cargo traffic types, which affirms the assumed hypothesis and justifies recommendations for future investment. It should be mentioned that the investment in modernization and maintenance of current infra and supra structure, such as quays, berths and especially storage capacities are needed. With the improved allocation of warehouse charterers as well as with covering of land space between warehouses no. 3 and 4, and also no. 4 and 5 (Figure 1) the larger space should be at disposal for interested parties. One of the largest issues is the lack of adequate cargo – handling equipment, which is insufficient and often used for diverse commodities increasing the overall costs but also increasing the working hours of individual crane. Moreover, with the projected cargo traffic increase in the observed period and as for the aim of the cargo manipulation of every concessionaire which is to perform the business processes more efficiently, the port alongside its concessionaries should prepare investment plan for procurement of additional harbour crane in the Vranjic – Solin basin and remaining equipment regarding the needs in specific terminals.

The planned infrastructural project of dislocation of the part of the RO-RO maritime traffic from the city port basin to northern cargo terminal would increase traffic on the access roads to the Vranjic – Solin basin while in the structure of maritime traffic RO-RO vessels with the occasional arrival of the largest passenger ships would prevail. The projects outcome predicts the increase in number of port calls in the Vranjic – Solin basin, which would result with several time more of annual vessel traffic than the current situation, so it is essential to perform these processes systematically to enable the proper development of the whole area. The positive effect on the development of the Split traffic route would be the integration of Adriatic-Ionian Transport Corridor in the Trans-European Transport Network by enabling faster traffic, economic development and easier access to the European markets [38]. Also, as for the strategic planning of the port development in order to increase the efficiency of the overall traffic from and to the port, the decision makers in the logistic chain should consider the possibility of construction of an inland intermodal terminal on the location in Labin Dalmatiski (Prgomet) as an development perspective which would resolve the problem of access from the cargo terminals to the highway and could also service air transport traffic. It should be emphasized that the strategic commitment exclusively on maritime passenger transport, cruise traffic and nautical tourism is unsustainable, as these specific forms are directly associated with tourism which in the long term, except in relation to tourism brands, represents risky, sensitive and uncertain development.

5. CONCLUSION

The Port of Split has great potential for the future development and expansion of the cargo traffic as a business activity, regarding all comparative advantages and available resources. The focus should be the modernization of infrastructure throughout the logistic chain, especially the reconstruction of the road and railways providing improved access to the cargo terminals. All entities involved in the production of the overall service of the cargo traffic activity in the Port of Split on the local, regional and strategic level, primarily the city of Split and Republic of Croatia, should support and indicate the strategic interest in the cargo traffic development.

REFERENCES

1. Maritime & Transport Business Solutions (MTBS). (2016) National Development Plan for Ports of Special International Economic Interest for Croatia, Ministry of the Sea, Transport and Infrastructure, Zagreb. Croatia. https://esavjetovanja.gov.hr/Documents/List/4553 [accessed: 14. 04. 2019]
2. Split port authority. (2018) Statistical data, Split. https://portsplit.hr/en/ [accessed: 20. 02. 2019]

3. Ministry of Tourism. (2019) Turizam u brojkama 2018, Ministy of tourism of Republic of Croatia. Croatian Bureau of Statistics, Zagreb. https://mint.gov.hr/UserDocsImages/AA_2018_cdokumenti/190614_HTZ%20TUB_2018_hrv.pdf [accessed: 14. 04. 2019]
4. Vukic, L., Ukic Boljat, H., Sliškovic, M. (2018), *Short Sea Shipping – an Opportunity for Development of the North Port of Split*. NAŠE MORE: znanstveno-strucni casopis za more I pomorstvo. Vol.65. No. 3 Supplement. pp. 18-25. doi:10.17818/NM/2018/3.10
5. Kos, S., Bakota, M., Brčić, D. (2018) *Analysis of the Impact of Transport Corridor Vc on the Port of Ploče*. Promet – Traffic & Transportation. Vol. 30. No. 4. pp. .465-477. doi:10.7307/ptt.v30i4.2656
6. Acciaro, M., McKinnon, A.C. (2013) *Efficient hinterland transport infrastructure and services for large container ports*. Position paper for the OECD/ITF Roundtable. Port Investment and Container Shipping Markets. Santiago de Chile. Chile.
7. Alamoush, ASM. (2016) *The impact of hinterland transport on port operational performance: a Jordanian case*, Doctoral dissertation. World Maritime University, The Maritime Commons: Digital Repository of the World Maritime University 536. http://commons.wmu.se/all_dissertations/536 [accessed: 14. 04. 2019]
8. Jurjević, M., Dundović, Č., Hess, S. (2016) *A model for determining the competitiveness of the ports and traffic routes*. Tehnički vjesnik – Technical Gazette. Vol.23. No.5. pp. 1489-1496. doi: doi.org/10.17559/TV-20140709100013
9. Split – Dalmatia County (2018) Izvješće o stanju u gospodarstvu Splitsko-dalmatinske županije s prikazom financijskih kretanja u 2017. godini i ostvarenju programa poticanja malog i srednjeg poduzetništva u Splitsko-dalmatinskoj županiji u 2017. godini. Upravnı odjel za gospodarstvo, europske fondove ı poljoprıvredu. Split. Croatia.
10. Port Authority Split (2017) Maritime study for berth and international passenger terminal in the North Port of Split (Stinice). University of Split, Faculty of Maritime Studies.
11. University of Split (2017) Strategy of Urban agglomeration Split. Available at: www.split.hr [accessed: 20. 02. 2019]
12. HŽ Infrastructure (2015) Network Report 2017. Croatian railways. http://www.hzinfra.hr/?page_id=5903 [accessed: 20. 02. 2019]
13. Port Authority Split (2015) Pravilnik o redu u luci uvjetima korištenjalukom na području luke Split. Split. Croatia. https://portsplit.hr/wp-content/uploads/PRAVILNIK-O-REDU-U-LUCI-lipanj-2015.pdf [accessed: 20. 02. 2019]
14. Luka d.d. Split (2018) Opis terminal. http://www.lukasplit.hr/services/terminal-za-rasuti-teret/ [accessed: 13. 03. 2019]
15. Ameropa Žitni terminal (2018). About us. http://www.ameropa-zitni-terminal.hr/en/Activities [accessed: 13. 03. 2019]
16. Port Authority Split (2018) Port areas. https://portsplit.hr/en/port-of-split/port-areas/ [accessed: 13. 03. 2019]
17. Luka d.d. Split (2018) Izvješće o mreži operatora. http://www.lukasplit.hr/izvjesce-o-mrezi-operatora/ [accessed: 13. 03. 2019]
18. Kos, S., Brčić, D., Karmelić, J. (2010) *structural analysıs of Croatian contaıner seaports*. Pomorstvo. Vol. 24. No.2. pp. 189-209.
19. Croatian Bureau of Statistics (2016) Statistical report. Intermodal transport 2014 and 2015. Zagreb 2016. https://www.dzs.hr/Hrv_Eng/publication/2016/SI-1587.pdf [accessed: 13. 03. 2019]
20. Port authority Split (2017) Port statistics. https://portsplit.hr/ [accessed: 13. 03. 2019]
21. Port authority Split (2017) Port Operations Centre Internal Report. Split. Croatia.
22. X-PRESS Feeders (2018) Routes and Schedules. https://www.x-pressfeeders.com/Home/RouteSchedule [accessed: 18. 05. 2019]
23. Maritime & Transport Business Solutions (MTBS). (2016) National Development Plan for Ports of Special International Economic Interest for Croatia, Ministry of the Sea, Transport and Infrastructure, Zagreb. Croatia.
24. Marine traffic (2018) Density maps. https://www.marinetraffic.com/ [accessed: 18. 05. 2019]
25. Ministry of the Sea, Transport and Infrastructure (2017) Transport Development Strategy of the Republic of Croatia (2017 - 2030). http://www.kormany.hu/download/9/9f/11000/00_HR_kozlekedesfejlesztesi_strategia_EN.pdf [accessed: 18. 05. 2019]
26. Poslovni (2018) Unska pruga ojačala bi luku u Gaženici. http://www.poslovni.hr/hrvatska/unska-pruga-ojacala-bi-luku-u-gazenici-344570 [accessed: 18. 05. 2019]
27. European Commission (2016) Transport. Marco Polo. http://ec.europa.eu/transport/marcopolo/about/index_en.htm [accessed: 18. 05. 2019]
28. Luka d.d. Split (2018) Internal documents. Split. Croatia.
29. Sadiković, M. (2018) Unska pruga - lijek za bosansku i dalmatinsku tugu. http://balkans.aljazeera.net/vijesti/unska-pruga-lijek-za-bosansku-i-dalmatinsku-tugu [accessed: 18. 05. 2019]
30. Krajina (2018) Unska pruga: Kineski investitori kao poklon s neba. https://www.krajina.ba/unska-pruga-kineski-investitori-kao-poklon-s-neba/ [accessed: 18. 05. 2019]
31. Croatian chamber of commerce (2018) GDP per County. Presentation of trends in the movement of the GDP of counties at the level of Croatia and the EU. April, 2018. https://www.hgk.hr/documents/bdp-po-zupanijama-u-2015-godini-final25ad8955342dfa.pdf [accessed: 18. 05. 2019]

32. European Commission (2019) Economic forecast for Croatia. https://ec.europa.eu/info/business-economy-euro/economic-performance-and-forecasts/economic-performance-country/croatia/economic-forecast-croatia_en [accessed: 18. 05. 2019]
33. Kelebuh, I. Pad industrijske proizvodnje u 2018. nakon četverogodišnjeg rasta. https://www.teb.hr/novosti/2019/pad-industrijske-proizvodnje-u-2018-nakon-cetverogodisnjeg-rasta/ [accessed: 18. 05. 2019]
34. Addiko (2018) Addiko: Rast BDP-a BiH u 2018. i 2019. od 3,1%, odnosno 3,5%. http://www.profitiraj.ba/addiko-rast-bdp-a-bih-u-2018-i-2019-od-31-odnosno-35/ [accessed: 18. 05. 2019]
35. Večernji list (2018) Industrijska proizvodnja u Federaciji BiH u 2017. veća za 3,8 posto. https://www.vecernji.ba/vijesti/industrijska-proizvodnja-u-federaciji-bih-u-2017-veca-za-3-8-posto-1223809 [accessed: 18. 05. 2019]
36. Rathman, D., Kružić, B., Poletan Jugović, T. (2015). *Analysis of the competitiveness of Port of Ploče at the container transport market and the possibilities for improvement*, Pomorstvo. Vol. 29. No.1. pp. 40-44.
37. Matamala, EL., Salas, GP. (2012) *Port-rail integration: challenges and opportunities for Latin America*. Bulletin FAL, ECLAC. Facilitation of transport and trade in Latin America and the Caribbean. Vol.310. No.7.
38. Puz, G., Radić, J. (2015). *The Adriatic - Ionian Transport Corridor*. Conference: IRF Europe & Central Asia Regional Congress 2015. Istanbul, Turkey.

THE MAXIMUM DURATION OF A CONCESSION FOR MARINAS IN CROATIAN AND COMPARATIVE LAWS

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Summary

One of the fundamental questions in successful economic exploitation of maritime domain is related to concession period regulation. The duration of a concession can be, and most often is, the main limiting factor for a development potential of the concessionaire. In Croatia, the duration of a concession contract depends on how relevant that marina is. According to the Maritime Domain and Seaports Act passed in 2003 (*lex specialis*), the duration of a concession for marinas of importance for the county is limited up to twenty years. For marinas of national importance for the Republic of Croatia, that time is limited up to fifty years. The duration of a concession may be extended if it is economically justified by the new investments on a maritime domain. In Italy, Spain and France the duration of a concession for marinas is different for each country. As a rule, the duration is fifty years or more. However, no matter how long concession periods really are, researches show that they are always too short for the marine concessionaires. The duration of a concession should be limited in order to avoid market foreclosure and restriction of competition. In that sense, Directive 2014/23/EU of the European Parliament and of the Council of 26 February 2014 on the award of concession contracts was adopted on EU level. This Directive has been transposed into Croatian legislation by means of the Concessions Act (*lex generalis*) which was adopted on 22nd of July, 2017. The aim of this paper is to analyze the duration and extension of the duration of concession for marinas in Croatia, France, Italy and Spain.

Keywords: marina, concession, extension of concession, comparative laws, EU law

1. INTRODUCTION

According to Article 3(2) of Maritime Domain and Seaports Act (hereinafter ZPDML, official gazette "Narodne Novine" (hereinafter: NN), nr. 158/03, 141/06, 38/09, 123/11 and 56/16), entered into force on 15 October, 2003: *Maritime domain is defined as internal waters and territorial sea, seabed and subsoil and part of the land that is naturally or by decision intended for public use, and also every area permanently connected to the land, on or under the sea surface*.

Article 3(3) of ZPDML determines what is considered part of the land: shore, ports, embankments, banks, cliffs, beaches, river mouths – that flow into the sea, watercourses connected to the sea, in the sea and under the sea – animate and inanimate natural resources.

This definition undoubtedly identifies that parts of maritime domain are sea water, sea bed and subsoil and that maritime domane is determined *ex lege*. The question is: which is the part of the land - and every area connected on or under the sea surface – that is naturally or by decision intended for public use?

The legal regulation does not explicitely determine that indisputable parts of maritime domain are immovables such as pier, waterfront, breakwaters, beaches etc., that often are marked as maritime domain in land registry. We believe that this should be done with the amendments to the Act.

Still, the definition of the maritime domain as common good (*res extra commercium*), i.e. the property right or any other right on any ground can not be acquired (over maritime domain Article 5(2), ZPDML), emphasizes the nature of maritime domain (Vuković, 2009).

On the other hand, previously existing Maritime Code of 1994 (hereinafter PZ/94, NN, nr. 17/94, 74/94 i 43/96) had indistinct and really dubious provisions on rights over maritime domain. Although the Maritime Code was based on *superficies solo cedit* principle some provisions treated separately buildings from the land, thus creating the fiction by which it would be possible not to apply the principle of homogeneity of immovable.

The Ownership and Other Property Rights Act (hereinafter ZVDSP, NN, nr. 91/96, 68/98, 137/99, 22/00, 73/00, 114/01, 79/06, 141/06, 146/08, 38/09, 153/09, 143/12 and 152/14), that entered into force on 1 January, 1997, as systematic law has provisions about the possibilty of breaking the principle of homogeneity of immovables on common goods, so it would be possible to own the construction built based on concession.

A crucial question arises: when PZ/94 was in effect was it possible to acquire the property right over construstions built on maritime domain, considering the ZVDSP? If we consider the fundamental principles of PZ/94, we believe that it wasn't possible, based on principle *lex posteriori derogat lege priori*.

Besides, ZPDML explicitly determined that all buildings and other constructions on maritime domain permanently connected with maritime domain are to be considered part of maritime domain (Article 5(1)), thus emphasizing the fact that the maritime domain and the constructions on maritime domain are in the same legal system. This attitude of legislators, i.e. not accepting the decision from Article 3(4) and Article 9(4) of ZVDSP, clears any existing doubt about legal status of constructions on maritime domain. That means that any property right or any other right (e.g. mortgage) can't exist during the period of the concession (Mišić, 2012). Unlike us, Bolanča (2005) has a different opinion on this matter.

The goal of this study is to examine how concession periods and their extension for nautical tourism marinas are regulated, not only in Croatia, but also in leading countries in Mediterranean nautical tourism, such as France, Spain and Italy.

2. CONCESSION ON MARITIME DOMAIN

In legal theory (especially in administrative law) the term concession is used very often (Đerđa, 2015). The reason is, among other things that concession is usually granted by administrative authority (Borković, 1995). This authority also establishes general terms and conditions of concession, supervises the execution of concession agreement and can take different measures against concessionaire (for non-execution contract obligations). This is the reason for the existance of many legal definitions of concession in administrative legal doctrine (Vojković, 2014).

According to ZPDML the concession is a right under which a part of maritime domain is partially or fully excluded from public use and is given for special use and/or economic exploitation to legal and physical persons registered as artisans, in accordance with zoning plans. At the same time High Administrative Court sentence nr. Usoz-116/16-6 of 25 April 2017 emphasizes that: „(…) *the existance of final individual act that grants certain rights does not prevent local administration authority, during local self-government activities with formal procedure, from regulating zone planning* (…)"

According to Article 3(1) of Concession Act (hereinafter ZOK, NN, nr. 69/17) concession right is granted by contract.

The topic of concession on maritime domain is regulated by ZDPM, by the Act on Procedures for Granting Concessions on Maritime Domain (Uredba o postupki davanja koncesije na pomorskom dobru, hereinafter Uredba 2004, NN, broj 23/04, 101/04, 39/06, 63/08, 125/10, 102/11, 83/12 i 10/17) and ZOK.

2.1. Preliminary actions for granting the concession for economic exploitation of a maritime domain

According to Article 7(4) of ZPDML, a concession on maritime domain can be granted after establishing borders of maritime domain and registration in Land Register (Staničić, Bogović, 2017).

This legal regulation probably was ment for a good cause, like organizing maritime domains records in Land Register. But, this good intention hasn't still met the authority's expectations, that is it didn't much improved recordings of maritime domain on one hand, and on the other hand it slowed down the granting of concession for economic exploitation of maritime domain. We don't need to emphasize the fact that registering of maritime domain in cadaster and in Land Register doesn't work as expected because it doesn't mirror the real situation.

In conclusion, we have to say that the above mentioned regulation has done so far significant economic damage because of the impossibility to grant concessions before registering a maritime domain in land register. It is obvious that our society is not enough organized yet in order to implement such regulation and we think that would be better to delay the implementation for better times.

As already mentioned, we think that is necessary to delay the application of regulation but also to present an amendment to said regulation and that the procedure for concessions granting shall be conditional upon the performing of geodetic survey after defining the border of maritime domain. That survey has to be certified by competent authority for cadastral affairs, and after certification maritime domain should be registered in cadaster and land registry. This approach to granting concessions wouldn't slow down the registration of maritime domain; it would allow simpler economic exploitation based on granted concessions.

According to Article 14 of ZOK preliminary actions for granting concessions are:

1. Forming an Expert Committe on Concession,
2. To carry out an economic feasibility study of concession granting or the analysis of concession granting, made by the subject that grants a concession,
3. Evaluating the value of the concession
4. Preparing documents for tendering.

According to Article 17 of ZPDML, a concession for economic exploitation of maritime domain can be granted to legal or physical person (artisan) if they meet following requirements:

1. They have to be registered for economic activities they are applying for in the concession bid
2. To have adequate technical, professional and organizational skills,
3. To have a guarantee to implement concession's plans and programs,
4. Not to have any debts from previous concessions,
5. Not to have previously lost a concession according to Article 30 of ZPDML.

According to Article 37(1) of ZPDML the government of Republic of Croatia decides procedure and criteria of concession granting. But, in practical application of Article 18(2) of Uredba 2004 we may notice vagueness regarding required documentation to attach to the concession tender and because of that it was difficult to choose the best bid; so an Amendment was made. The Amendment of 2017 implements the list of concession economic activities, determines the basis for calculating a variable part of concession fee for economic exploitation of shipyards and changes the criteria for evaluating tenders. The most important part of the tender is the economic feasibility study. The total amount of the investment planned in the economic feasibility study is considered to be the investment in the capital assests.

2.2. Period of concession for economic exploitation of a maritime domain

According to the Article 20(2) of ZPDML, County Assembley grants the concession for economic exploitation of maritime domain and for exploitation or construction of important buildings for County, for a maximum 20-year period and local administrative authority is in charge of preliminary formal procedure.

Republic of Croatia's government grants the concession for economic exploitation of maritime domain that inculedes construction of buildings of national significance for maximum 50-year period and Ministry is charge of preliminary formal procedure (Article 20(3) of ZPDML).

According to Article 20(4) of ZPDML a concession that includes construction of new buildings of national significance that needs great investments and whose economic impact can't be fully accomplished in 50 years, can be granted for more than 50 years by the government, with previous authorization of Parliament. Zone planning regulations determine which buildings are of national significance, and all other buildings are of County significance. The Act on buildings, other spatial interventions and areas of national and regional significance (NN, nr. 37/2014) determines buildings and areas of national significance and buildings and areas of regional significance. Article 2(1) first subparagraph fourth indent of this Act determines that all special purpose ports that are not of national significance are of regional significance.

Article 17(2) ov ZOK regulates that concession granting authority determines a concession period so that this period doesn't limit market competition more than necessary to ensure the amortization of the real value of the concessionaires investment and reasonable investment return, considering both expences and risks for the concessionaire during the concession period.

Speaking of concession periods determined by ZDPL and Uredba 2004, we have to say that legislation hasn't consider this very important matter for concassionaires and didn't take into account legal and economic consequences of short concession periods. That is the reason why already in preliminary procedures, before the decision of granting a concession is implemented, periods of concession are superficially considered: that means that concession periods are decided at complete discretion of concession granting authorities, who evaluate *ad hoc* every single concession for economic exploitation of maritime domain.

In fact, the practice shows that already expert bodies suggest short terms for concessions, but without valid argumentation. Basic reason for this poor term suggestion is the fact that the existing regulation isn't based on scientific and professional arguments.

Our thesis is confermed by different interpretations of Article 16 of Uredba 2004. According to this Article, *inter alia*, the initial amount of concession fee for special purpose ports (new unbuilt marinas) is calculated, among other things, based on square meters: 2 HRK/m2, and the variable part is 2% of concessionaire's profit.

Although this is a general act, applicable to all concession granting authorities, we noticed great application differences, depending on authority. For example, Split-Dalmatia County in Decision on Intention to Grant Concession on Maritime Domain in order to build and use special purpose port – nautical marina in cadastral municipality Jesenice, Bajnice area, Municipality of Dugi Rat, defines a 20-year time period for a concession and total area of 32242 m2 (12951 m2 land area and 19291 m2 sea area). The initial price for the fixed part of concession fee is 200.000,00 HRK per year, and variable part is 5% of concessionaire's profit, made with the economic exploitation of concession. On the other hand, Republic of Croatia's government in Decision on Intention to Grant Concession on Maritime Domain in order to build and use special purpose port – nautical marina in Sućuraj, defines a 30-year period for a concession and total area of 100.251 m2. The initial price for fixed part of concession fee is 2 HRK/m2, i.e. 200.502,00 HRK, and variable part is 2% of concaccionare's annual profit made with the economic axploitation of concession.

All the above indicates diverging practices in the application of the existing law in procedures of concession granting. In this way, concessionaires have an unequal position regarding the period of concession and the initial price for fixed part of concession, depending on different concession granting authorities.

First of all, we think that is necessary to prescribe more detailed and more precise criteria for determining the initial concession fee and concession period in ZPDML and Uredba 2004. One of the penalties for non-compliance with those measures coud be the possibility of annulment of concession granting procedures.

However, we think that measures have to be taken to assure the equal market competition for a concessionaire, who should not depend on different concession granting authorities (government or county).

2.3. Concession period and the extention of concession period for nautical tourism marinas

Marina, dry marina, mooring and boat storage ashore are nautical tourism marinas. Nautical tourism marinas are apecial purpose ports (Article 42 of ZPDML). For Grabovac (1993): "[…] *special purpose port has so called special purpose, and principle of equal treatment does not apply to special purpose port's use."*

According to Article 80(4) of ZPDML, concession for special purpose use is granted:

1. By County Assembly for ports of county importance for a 20-year period,
2. By Croatian government for ports of national importance for up to a 50-year period,
3. By Croatian government with a consent of Croatian Parliament for ports of national importance for more than 50 years.

If we analyse the criteria for the implementation of concession granting procedures by the County or by the government it becomes obvious that there is no clear reason to grant the concession for construction and economic exploitation of nautical marinas for a period of 20 years on county level and for a period of 30 – 50 years on national level. The reason is not even economic, because the concessionaires who have shorter concession periods, among other things, don't have necessary time for amortization of the investment, especially for investments in marinas and in other nautical tourism ports. The concessionaires, who accepted this unfavourable concession conditions also warn about this problem, hoping that this issue will be better regulated with amendments or with new regulation about concession periods on maritime domain.

According to Article 17(6) of ZOK, the period of concession for economic exploitation of public or other good can be extended according to special act provisions.

We already pointed out that special Act for maritime domain concessions is ZPDML. According to the Article 22(1) a county assembly can, in exceptional cases, extend the concession period to 30 years, upon concessionaire's request and with the authorization of the Croatian government, if new economic investments justify the extention and in case of force majeure.

In order to reassure the concessionaires to some to some extent, and of course under certain circumstance, future amendments of ZPDML should give the possibility to the counties to grant concessions for a 30-year (and not 20-year) period and regulate better the possibility to extend the concession even after the expiry of concession period.

We also think that counties should be given the authority, with a consent of Croatian government, to extend the concession period upon concessionaire's requesto to 50 years, if new economic investments justify the extention and in case of force majeure

In fact, we think that this time period for economic exploitation of concession is justified because it would stimulate conceccionaires to invest more in the development of business activities in the area of concession and allow them to amortize their investment. Longer concession period would also put in more equal position concessionaires who were granted the concession by the County and by the government or Port Authority for public transport ports. In this context it is emportant to emphasize Degan's opinion (2017) who thinks that: *„[…]for big investments, for example in ports, a concession period can be a 30, even 40, or in exceptional cases 50-year period. A 100-year period concession means completely taking away the area of concession. This kind of concession is by its nature fraudulent."*

According to Article 22(2) of ZPDML Croatian government can exceptionally, upon concessionaire's request - for a concession that involves the construction of national importance buildings - extend the concession period up to 60 years. For example, government rendered a Decision to Grant Concession on Maritime Domain in order to build and use special purpose port – nautical marina Marina Kaštela (NN, nr. 136/13) and extended the concession period to 30 years because of the new investments in unique port area and in order the construction could be finished. Previously County granted a concession for a 12-year period from the day of the Concession Agreement (Official Gazette, nr. 9/04).

Considering that concessionaires who have a concession for constructing and economic exploitation of maritime domain – port area, usually marinas, are making big investments in concession areas and those investments are not amortized durin the period of concession, the question is how to treat those investments and the compensation for the investments? Usually, a new tender with certain tender criteria is announced after the expiration of concession period, but the next concessionare doesn't have to compensate the investment that is not amortized. Given that concession areas have an increased value the question is what to do in those cases and how to treat that investments.

We think that an authorized court expert should evaluate the invested and not amortized capital that increased the value of maritime domain. Based on the expert evaluation one of new tender conditions should be the compensation of the investments or the the concession granting authority should compensate the investment, i.e. the Republic of Croatia as direct maritime domain management authority.

We think that in such cases instead of ZPDML Rules of Unjust Enrichment should be applied, according to the Article 111 of Obligative Relationship Act (Zakon o obveznim odnosima (NN, broj 35/05, 41/08, 125/11, 78/15 i 29/18.) (Vuković, 2015).

2.4. Influence of directives 2006/123/EC and 2014/23/EU on concession periods and extensions of concession periods for marinas

Two Directives are relevant regarding concession periods for maritime domain: a) Directive 2006/123/EC of the European Parliament and of the Council of 12 December 2006 on Services in the Internal Market [SL L 376, 27/12/2006 (hereinafter: Directive on Services)] and b) Directive 2014/23/EU of 26 February 2014, on the Award of Concession Contracts [SL L 94 28/3/2014 and Amendments 2014/23/EU of the European Parliament and the Council of 26 February 2014 ,on the award of concession contracts SL L 114, 5/5/2014. (hereinafter: Directive on Concessions)]. Those two Directives set minimum standards that member states have to transpose into internal law systems.

The Directive on Services does not apply to marinas because except for services on public property there are other activities done in marinas, such as construction and economic exploitation of maritime domain. This Directive is implemented in Services Act (NN, nr. 80/11). The application of Directive on Concessions usually depends on value limit (5.548.000,00 EUR on 1/8/2018). This Directive does not apply to concessions under this limit, but it is applied to concessions above this limit (Article 8). A procedure of concession granting for services and economic exploitation of public or other propriety whose value is equal or bigger than the value limit, is applied to concessions for economic exploitation of marinas, whose value is equal or bigger than the value limit (Title IV of ZOK), except Articles 42, 44, 49, 50, 52 and 53 of ZOK (Article

40(1) of ZOK). This is apparent from the Noticfication of Concession Granting on Maritime Domain in order to build and use special purpose port – nautical marina in Sućuraj (available at www.vlada.gov.hr). The concession granting authority – Croatian government – refers to the authority from Article 80(4) Title 2 of ZPDML, concerning the Article 31(1) and (2) of ZOK. In the explanation of this Notification we can see that the estimated value of the concession in above the limit (443.963.728,00 HRK for a 30-year period), but since we are dealing with the economic exploitation of maritime domain the procedure is done according to the regulation from Article 31(1) and (2) of ZOK.

The Directive on Concessions determines that the concession period is limited, but it doesn't determines the duration of concession periods (Article 18). According to Article 43 of this Directive, concessions can undergo changes without a new tender in strictly defined cases. It won't be possible to extend the concession period according to the Article 22 of ZPDML for marinas whose concession is above the value limit and it was granted after 22 July 2017, that means after the transposal of Directive on Concessions in Croatian law. In those cases the only possibility is the extention of the contract when it is necessary to make changes in concession contract (Article 17(5) of ZOK), (Tuhtan Grgić, Bulum, 2018).

3. COMPARATIVE LAWS

3.1. Spain

Coastal Act of 1988 (*Ley 22/1988, de 28 de julio, de Costas*) (Official gazzette, Boletin Oficial del Estado - BOE, nr. 181, of 28/7/1988) determines that the maritime domain *(dominio publico)* is of public property and automatically all real rights are lost on maritime domain. *This Law transformed the rights of private owners whose properties were within the public domain. They were given a right of occupancy of their properties for thirty years. This concession can be extended another thirty years* (Negro, Lopez-Gutierrez, Esteban, Matutano, 2014) . Every occupation of public area has to be previously authorized by a concession, granted by State authority. Concessions for marinas are under counties' authority (*Comunidades Autononomas*). Counties independently regulate concession granting and nautical ports exploitation (Caorsi, 2004).

The concession period on maritime domain can't be longer than 30 years in any case. But, when the expired concession is included in other concession for mineral or energy resource exploitation granted by the authority for a longer period, the concessionare has right to have a new concession for exploitation, for the equal period of time as the valid concession for mineral or energy resources exploitation, but not longer than 30 years (Article 66 of Coastal Act).

The Act on Protection and Sustainable Exploitation of Coastlines and the Coastline Act Amendment *(Ley 2/2013, de 29 de mayo, de protección y uso sostenible del litoral y de modificación de la Ley 22/1988, de 28 de julio, de Costas) (BOE, nr.129. of 30/5/2013)* have modified concessionaires rights. The new rule is that a concession period on maritime domain may not be longer than 75 years. Each concession can be extended, according to the legal criteria, but always respecting the 75-year limit. Exeptionally, when the expired concession is included in other concession for mineral or energy resource exploitation granted by the authority for a longer period, the concessionare has right to have a new concession for exploitation for the equal period of time as the valid concession for mineral or energy resources exploitation, but not longer than 75 years (Noticias Juridicas 2019). As for concessions granted based on Coastline Act of 1988, they can be extended and are equal to new concessions. That means that all concessions that should expire in 2018 after 30 years, can be extended up to 75 years (FEAPDT, 2019).

The transposition of Directive on Concessions is done in the new Public Procurement Act *(Ley de contratos del sector publico) (BOE, nr.272. of 9/11/2017)* that enterd into force on 9 March 2018.

3.2. France

In France General Public Property Code enterd into force on 1 June 2006 (*Code general de la propriete des personnes publiques)* (Official Gazzette, Journal official de la Republique francaise – JORF, of 22/4/2006.) that explicitly prescribes that maritime domain iz state property. There is a difference between natural maritime (*naturel domain public maritime*) domain and artificial public domain *(artificial domain public martime).* The area of natural maritime domain is regulated by Article L2111-4, and the area of artificial maritime domain by Article L2111-6 of this Code. Special laws regulate the management of all public – state properties.

According to the Article R-5314-30 of Transport Code *(Code des Transports, Version consolidée au 15 février 2019.*) (JORF, nr.5. of 6.1.2016.), a concession for marina is granted for a 50-year period if the goal of concession is the exploitation or construction of port infrastructure or superstructure. Other types or concessions cant be granted for periods longer than 35 years *(Les concessions d'établissement ou d'exploitation d'infrastructures ou de superstructures portuaires ne peuvent être consenties pour une durée supérieure à cinquante ans. Les autres concessions, conventions et autorisations d'occupation de toute nature du domain public ne peuvent être consenties pour une durée supérieure à trentecinqe ans).*

The procedure of granting a concession on every seaport has to be open, transparent and non-discriminatory. In France the concession can't be automatically extended (Kundih, 2018).

The transposition of the Concession Directive was expected following the earlier transposition of the European directives 2014/24/EU and 2014/25/EU on public procurement dated 26 February 2014 on public procurement (which occurred in France on 23 July 2015). While preserving certain specificities of French law, the Ordinance and the Decree aim to simplify, clarify and unify the existing legal framework governing the award and implementation of concession contracts in accordance with recent French and European case law. This new single legal framework applicable to concession contracts will enter into force on 1 April 2016 and replace the legal provisions currently applicable (in particular "loi n° 93-122" dated 29 January 1993 and "ordonnance n° 2009-864" dated 15 July 2009. (Bouillon, Vaissier, Seniuta, 2016).

3.3. Italy

The Civil Code of 1942 which, in Article 822(1) identifies the category of "State-owned maritime property", consisting of the seaside, beaches, ports and harbours. Together with the assets of State-owned water properties and those of military ownership, the State-owned maritime property assets have been placed in the overall category of "State-owned property", characterised by their belonging to the state. However, the definition of a complete and organic State-owned maritime property system is due to the same sector regulations contained in the Italian "Codice della navigazione". The Code has primarily operated a specification and extension of the notion of State-owned maritime property contained in the Civil Code, identifying in Article 28 further categories of assets, according to a principle of continuity and contiguity of the coasts with respect to a specific destination, referred to as "public uses of the sea". Regarding the definition of the notion of "public use", the same Code has accentuated the power of choice of public administration through identifying the legal arrangement of the concession, which, pursuant to Article 823(1) of the Italian Civil Code, mitigates the banning of rights in favour of third parties on State-owned maritime property, given the inalienability of such goods. (European Parliament, Policy Department C: Citizens' Rights and Constitutional Affairs, Italian state beach concessions and Directive 2006/123/EC, in the European context, Italian state beach concessions and Directive 2006/123/EC, 2016).

Concession period on maritime domain is regulated by Article 36 and Article 37 of Navigation Code (Codice della Navigazione) (Official Gazzette Gazzetta Ufficiale – GU, nr. 93 of 18/04/1942). According to Article 36(1) of this Code a concession on maritime domain is granted for a limited period of time. Concession periods are defined in Article 36(2): i) concession periods longer than 15 years are under the Ministry of Transport and Navigation authority, ii) concession periods longer than 4 but shorter than 15 years are under the Marine Direction authority, iii) concession periods sup to 4 years are under the Chief of Marine Department authority.

According to the Article 37(1) of the Navigation Code if there is more than one concession bid, the bidder that gets priority is the one who can give better guarantees for profitable exploitation of concession and, at the same time, can suggest better exploitation of maritime domain in the best public interest, according to the evaluation of marine authority. Speaking of concessions on maritime domain for tourist and recreational activities, offers that include easy removable equipment have priority, in order to protect the marine environment (Article 37(2) of Navigation Code).

For the development of nautical tourism is very important the Ordinance on procedures of granting a concession on maritime domain for building constructions for nautical tourism (GU, nr. 40, of 18/02/1998). It is important for several reasons: i) a new nautical tourism port classification is legaly regulated as follows: marinas, multipurpose ports and moorings (Ugolini, Ivaldi, 2017); ii) concession granting procedure in those ports has been simplified (Benevolo, Spinelli, 2018); and iii) the possibility to extend the concession period if the concessionair will make new investments needed for port functioning (Article 10).

Concession period for marinas is the longest, up to 50 years (Senato della Repubblica Italia, 2017), considering the time for amortization of investments in marinas and other nautical tourism ports.

The Directive on Concessions is transposed in Public Contracts Code (Codice del Contratti Pubblici, GU, nr.91. of 19/04/2016.).

4. CONCLUSION

The exploitation of maritime domain is based on concession. The period of concession is defined in the contract between the concessionaire and the concession granting authority, based on decision to grant a concession. The extention of a concession period is an exception from the rule.

Directive on Concessions is a legal act of European Union that limits concession periods to the contract arranged periods. For concession periods longer than 5 years, the longest concession period won't exceed the period during which the concdessionaire could amortize the investment for constructions or services and have an appropriate return on the investments, considering the investments needed for special goals of contract. Concessions can be changed without new bidding procedure only in justified cases (Article 43 of Directive on Concessions).

Reaserch shows that different states – Croatia, Spain, France and Italy – transposed this Directive into their state laws in different moments. Spain was the last state to transpose it in the Public Procurement Act of 09/03/2018. The resistance has to be put in broader context. Spanish authorities declare that up to 75-year concession period protects concessionaires' interests and their reasonable expectations about their investments in maritime domain. But, it is reasonable to say that such a long concession period means ignoring market competition rules of the EU.

France and Italy, likewise Spain, regulated their concession periods and granted concessions for marinas for 50 years before transposing the Directive on concessions into their law systems. However, no matter how long concession periods really are, researches show that they are always too short for the marine concessionaires.

The biggest issue in Croatia is too high extent of discretional decision – making of the subject that grants concession. Arbitrariness includes: i) determination of the initial amount of concession fee, ii) extension of concession period and iii) compliance of the value limit. Therefore, the initial amount of the concession fee should be equal for marinas of county and national significance. The Article 22. of ZPDML permits the extension of the concession period but fails to prescribe the procedure for the extension authorization as well as criteria for the decision for the extension of concession period. The value limit defined in the Directive on Concessions should be complied with, in case of both marinas of county and national significance. In this way the procedure for concessions granting should be transparent what is legitimate expectation of all interested parties.

REFERENCES

[1] Benevolo, C., Spinelli, R.: The quality of web communication by Italian tourist ports, TOURISM, Vol. 66/ No. 1/ 2018/ 52 – 62.

[2] Bolanča, D.: Pomorsko dobro, Inženjerski biro, Zagreb, 2005., pp. 253.

[3] Borković, I.: Koncesije i pomorsko dobro, Zbornik radova Pravnog fakulteta u Splitu, Split, 1995., pp. 6-8.

[4] Bouillon, J., Vaissier, F-G., Seniuta, A.: Transposition of the Concession Directive in France. Avaiable at: https://www.jdsupra.com/legalnews/transposition-of-the-concession-76033/

[5] Caorsi, Y. R.: Amarres y puertos deportivos. Available at: http://www.nauticalegal.com/es/articulos/puertos-y-amarres/60-amarres-y-puertos-deportivos.

[6] Degan, V. Đ.: Pravna narav pomorskoga dobra, PPP vol. 56, no. 171, pp. 5-18, 2017.

[7] Đerđa, D., Koncesije, Hrvatska pravna revija, vol 15, no.2, 2015, pp. 55–64.

[8] European Parliament, Policy Department C: Citizens' Rights and Constitutional Affairs, Italian state beach concessions and Directive 2006/123/EC, in the European context, Italian state beach concessions and Directive 2006/123/EC, 2016. Available at: http://www.europarl.europa.eu/RegData/etudes/STUD/2017/596809/IPOL_STU(2017)596809_EN.pdf.

[9] FEAPDT. Available at: https://feapdt.es/.

[10] Grabovac, I.;Pomorsko pravo, Split, 1993.

[11] Kundih, K.: Neka otvorena pitanja upravljanja lukama nautičkog turizma u Franuskoj, Hrvatsko pomorsko dobro – Stručni portal. Avaiable at: https://www.pomorskodobro.com/prijedlozi/590-neka-otvorena-pitanja-upravljanja-lukama-nautickog-turizma-u-francuskoj.html

[12] Mišić, Ž. : Kritički osvrt u odnosu na važeće propise s prijedlogom mjera za kvalitetnije upravljanje pomorskim dobrom, PPP, vol. 51, pp. 295-333.

[13] Negro, V., Lopez – Gutierrez J-S., Esteban, M.D., Matutano, C., An analysis of recent changes in Spanish Coastal Law. Journal of Coastal Research, Special Issue No. 70, pp. 448-453. Available at: https://bioone.org/journals/journal-of-coastal-research/volume-70/issue-sp1.

[14] Senato della Repubblica Italia, Concessioni demaniali marittime, lacuali e fluviali ad uso turistico-ricreativo A.S. 2957. Avaiable at: https://www.senato.it/service/PDF/PDFServer/BGT/01059375.pdf.

[15] Staničić, F., Bogović, M.: Koncesije na pomorskom dobru – odnos Zakona o koncesijama i Zakona o pomorskom dobru i morskim lukama, PRAVNI VJESNIK, vol. 33 no. 1, 2017.

[16] Tuhtan Grgić, I. Bulum, B.: Problem valorizacije zakonitih ulaganja u lukama nautičkog turizma u Republici Hrvatskoj, PPP vol. 57, no.172, pp. 299–337, 2018.

[17] Ugolini, G. F., Ivaldi, E.: Tourist Ports and Yachting: The Case of Sardinia, Revista de Estudios Andaluces, vol. 34, núm. 1 (2017) pp. 429-452. Avaiable at: http://institucional.us.es/revistas/andaluces/34/ARTICULOS/Art15.pdf.

[18] Vojković, G.: Novi pravni okvir koncesija u Republici Hrvatskoj, Zbornik radova Pravnog fakulteta u Splitu, vol 51, no. 1/2014., pp. 131.- 149.

[19] Vuković, A.: Ulaganja u pomorsko dobro – studija slučaja t.d. Mornar d.d., Makarska, Hrvatsko pomorsko dobro – Stručni portal, 2015. Available at: https://www.pomorskodobro.com/fokus-vukovic-sijecanj-2015.html

[20] Vuković, A: Stečena prava na pomorskom dobru, Zbornik radova Pravnog fakulteta u Splitu, vol. 46, no.2/2009., pp. 373-389.

THE METHOD OF OPTIMAL CONTROL OF THE SHIP IN A COLLISION SITUATION

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Summary

The issues of ship traffic safety at sea are still valid. For this reason, shipbuilders equip them with various types of systems which assist during assessing the situation and making the right decision in the presence of a threat to maritime traffic safety. The problem of searching for effective methods for preventing collisions of ships has gained importance as the size, speed and number of vessels involved in sea traffic have increased. The radar, and later the anti-collision system which allows for the collision risk assessment and the simulation of a safe maneuver, contributed to a significant increase in the safety of navigation. Along with the development of computer technology and optimization methods, anti-collision systems have been able to choose the optimal maneuver due to the collision risk factor. In recent years, there have been tendencies to formulate optimization tasks assessing the solution of the collision situation not only from the point of view of traffic safety, but also due to the economic aspect of control. In the paper, an attempt was made to develop a method for determining the minimum-time control of the ship being in a collision situation with another vessels. Based on the developed method, simulation tests were carried out. The results confirmed the correctness of the developed method. The simulation results for the critical case, i.e. a parallel approaching of two vessels, are also presented.

Keywords: collision situation, time-optimal ship control

1. INTRODUCTION

Peter Padfield in [10] says "OOW (officer on watch) of ships are not reckless, careless maniacs with little sense of responsibility, with some worth-noting exceptions, who ram into each other in a fit of complete absentmindedness. OOW are simply people who face tasks impossible to do, trying to sail from point A to B in the time set and avoiding a collision with other ship which also tries to sail past them. Yet neither of them knows what the other is going to do or even what the other ship is obliged to do in given circumstances".

For these reasons the OOW, ship-owners and ship designers are interested in problems of safe navigation. Therefore in order to increase the safety of navigation and to reduce the losses resulting from the unexpected collisions, the ships have been equipped with a variety of systems which help officers on watch to assess the situation and also make the right decision in case of danger to the safety of navigation at the sea [14]. Such systems are referred to as collision avoidance systems. The problem of searching for effective methods to prevent ships from colliding has gained significance with the increase in speed, size and number of ships taking part in sea traffic [6]. The development of radar and then the collision avoidance systems, which can be used as a tool to asses the risk of collision and simulate safe maneuvers, have contributed largely to increasing the safety in navigation [7], [8], [15].

International regulations concerning the safety of navigation, determine the manner of undertaking anti-collision maneuvers in the situation of meeting two ships in conditions of good visibility, while in the case of a collision situation with a larger number of vessels they do not define way of maneuvering. Therefore, there is a need to develop navigator decision support systems aimed at improving the safety of navigation, which was expressed inter alia in the works [4], [9], [11]. The proposed solutions are more and more important in modern ship management systems [3] not only because of improved safety, but also due to the economics of shipping [15].

In navigational decision support systems, the problem of safe ship movement is defined as follows: we have object with specific dynamic and kinematic properties which is moving in given environment and which should find the path of transition between the starting and ending points, avoiding static and dynamic obstacles and taking into account other optimization criteria [5]. The problem of searching for a safe trajectory of traffic is wildly discussed and there are many ways to solve it. In literature has been presented algorithms for finding safe paths with the use for example genetic algorithms [12], [13] or game theory [6], [7] as well as many others.

With development of computer technologies and optimization methods, in collision avoidance systems are used solution which can choose an optimum maneuver based on indicator of collision's risk. In the last years, new tendencies have appeared in setting optimization tasks assessing the solution to a collision-like situation not only according to safety of navigation but also taking into account economic aspect of control [2], [15]. Therefore, in this work, an attempt was made to develop a method of determining the safe maneuver in the collision situation of sailing objects, while ensure optimal control with regard to time. The developed method allows to determine the minimal-time control of ship's movement in collision situation with simultaneous optimization of safety indicator.

2. FORMULATION OF THE PROBLEM

For further considerations it is assumed that angle of drift $\beta = 0$ and the ship are not affected by any disturbances. Under these assumptions, the problem of optimum ship control in a collision situation with a larger number of sailing objects can be formulated as below.

Equations of own ship movement in relation to velocities are known and described in the form of the following differential equations:

$$\begin{aligned} \frac{dV_0}{dt} &= a_2 n V_0 + a_3 {V_0}^2 + a_4 n^2, \\ \frac{d\psi_0}{dt} &= \omega_z, \\ \frac{d\omega_z}{dt} &= c_5 {V_0}^2 \omega_z + c_6 {V_0}^2 \alpha + c_8 V_0 \omega_z, \end{aligned} \tag{1}$$

where: $a_2, a_3, a_4, c_5, c_6, c_8$ – coefficients dependent on the ship dimensions, $V_0, \psi_0, \ \omega_x, n, \alpha$ – ship's speed and course, angular speed of turn, rotational speed of the propeller and angle of rudder blade deflection.

Equations of two-sided constraints can be written as follows:

$$\begin{aligned} \frac{dD_j}{dt} &= -V_0 \cos\left(N_j - \psi_0\right) + V_j \cos\left(N_j - \psi_j\right), \\ \frac{dN_j}{dt} &= \frac{V_j\left[\sin\psi_j + \cos\left(N_j - \psi_j\right)\sin N_j\right] - V_0\left[\sin\psi_0 + \cos\left(N_j - \psi_0\right)\sin N_j\right]}{D_j \cos N_j}. \end{aligned} \tag{2}$$

One-sided constraints are imposed on a ship which result from technical limitations and the limitations imposed on the vector of ship control $u^0 \in U^0$,

$$\begin{aligned} &\alpha^2 - \alpha_{\max}^2 \le 0, && 0 \le \bar{h} \le 1, \\ &0 \le \dot{\alpha} \le \dot{\alpha}_{\max}, && u_\alpha^2 - 1 \le 0, \end{aligned} \tag{3}$$

where: $\bar{h}, u_\alpha$ – control vector coordinates: position of the fuel slat and the signal sent to the steering unit, respectively.

The coupling relations are as follow:

$$\begin{aligned} \frac{dn}{dt} &= \frac{K_h}{2\pi I_\omega}\bar{h} - \frac{M_s}{2\pi I_\omega}, \\ \frac{d\alpha}{dt} &= \dot{\alpha}, \\ \frac{d\dot{\alpha}}{dt} &= -\frac{1}{T_{MS}}\dot{\alpha} + \frac{k_{MS}}{T_{MS}}u_\alpha. \end{aligned} \tag{4}$$

where: k_{MS}, T_{MS} - parameters of steering unit.

The ship's trajectory is defined as straight line sections between successive points of return (x, y) in a fixed rectangular coordinates system referred to earth.

In the inertial frame of own ship, the equations of motion of encountered objects are known and they are described by differential equations in form (1).

In the general case, the own ship is in a collision situation with encountered M-objects which current positions in relation to the own ship are known, it means: bearing N_j, distance D_j and current parameters of movement: speed V_j and course ψ_j.

To goal is to find such control for which the minimum distance $D_{\min}^j$ of approaching the j-th encountered object is larger than the safe distance D_b resulting from geometric dimensions of objects which are in the collision situation, and from the dynamics of navigational situation, i.e. the control for which the condition $D_b \le D_{\min}^j$ is satisfied.

In the process of searching for the control, the optimization criterion is taken into account in the form of the smallest loss of time which leads to the time-optimum control. Assuming that the initial time for the maneuver is $t_0 = 0$ and $t_k = T_{D\min}^j$, the quality criterion can be formulated as follows:

$$I = \int_0^{T_{D\min}^j} dt \tag{5}$$

3. SOLUTION OF THE PROBLEM

The problem formulated above is reduced to searching for the time optimum control affecting the ship which allows to avoid a collision with the encountered obejcts. To solve this problem, it is necessary to take into account the safe distance of approaching D_b (Fig. 1) in the kinematic model of the process. Thus, one of the constraint equations will be changed. It follows from Fig. 1 that in the case of passing the encountered object in front of its bow at a safe distance, the relation between bearing and safe distance can be written as follows:

$$N_j^1 = N_j - \arcsin\frac{D_b}{D_j} \tag{6}$$

whereas in the case of passing the encountered object behind its stern, the relation can be written as follows:

$$N_j^2 = N_j + \arcsin\frac{D_b}{D_j} \tag{7}$$

These dependences will be referred to as anticipated bearing. By differentiating these equations with respect to time and substituting dependences (2), we obtain:

$$\begin{aligned} \dot{N}_j^1 = &\left(\frac{1}{D_j} tgN_j + \frac{D_j D_b \sqrt{D_j}}{D_j^{\,2} + D_b^{\,2}}\right)\left[V_j \cos\left(N_j - \psi_j\right) - V_o \cos\left(N_j - \psi_o\right)\right] + \\ &+ \frac{V_j \sin\psi_j - V_o \sin\psi_o}{D_j \cos N_j} \end{aligned} \tag{8}$$

$$\begin{aligned} \dot{N}_j^2 = &\left(\frac{1}{D_j} tgN_j - \frac{D_j D_b \sqrt{D_j}}{D_j^{\,2} + D_b^{\,2}}\right)\left[V_j \cos\left(N_j - \psi_j\right) - V_o \cos\left(N_j - \psi_o\right)\right] + \\ &+ \frac{V_j \sin\psi_j - V_o \sin\psi_o}{D_j \cos N_j} \end{aligned} \tag{9}$$

The task is to find the minimum of functional (5) with conditions in the form of constraint equations (1), (3), (4), (8), (9) [1]. The function minimizing the functional (5) is searched for among variables $V_0, \psi_0, \omega_z, n, D_j,\ \zeta_1, \zeta_2, \zeta_3, \zeta_4, \zeta_5\ N_j^1$ or N_j^2. For this purpose, function $F\left(y, \dot{y}, t\right)$ is assumed in the form:

$$F(\bullet) = 1 + \sum_{i=0}^{n} \lambda_i\, \varphi_i \tag{10}$$

for which the Euler-Lagrange equations are determined from the relation:

$$\frac{\partial F}{\partial y_i} - \frac{d}{dt}\frac{\partial F}{\partial \dot{y}_i} = 0 \tag{11}$$

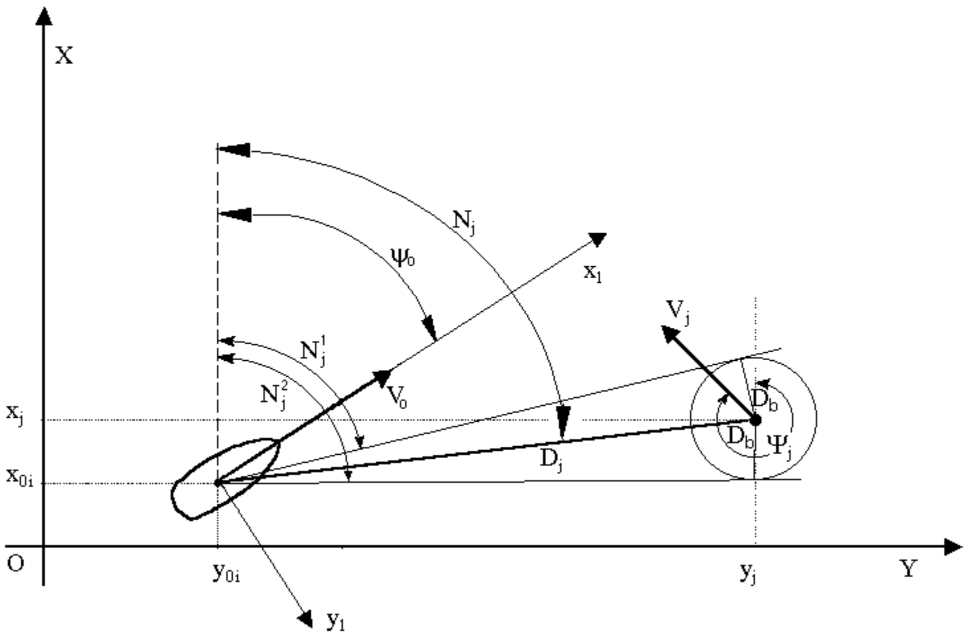

Figure 1 Kinematic relations in complex movement with safe distance of passing taken into account

The movement control of ship is executed by means of changing its speed or course. For further considerations it will be assumed that the collision avoidance maneuver will be executed by changing the course of the ship. In such a case it is assumed that V_D and n are constant and the limitations imposed by change of the position of the fuel slat $\overline{h}$ are not taken into account; thus the Euler-Lagrange equations for individual variables are as follows:

1. For variable $\psi_0: -\lambda_4 V_0 \sin(N_j-\psi_0) - \lambda_5 V_0\left(\frac{1}{D_j} tgN_j \pm \frac{D_j D_b\sqrt{D_j}}{D_j^2+D_b^2}\right)\sin(N_j-\psi_0) + \frac{\lambda_5 V_o\cos\psi_o}{D_j\cos N_j} - \dot{\lambda}_2 = 0.$

2. For variable $\omega_z:\ -\lambda_2 - \lambda_3 c_5 V_0^2 - \lambda_3 c_8 V_0 - \dot{\lambda}_3 = 0.$

3. For variable D_j:

$$-\lambda_5\left(\frac{-1}{D_j^2} tgN_j \pm \frac{1.5D_b\sqrt{D_j} - 0.5D_j D_b\sqrt{D_j}}{\left(D_j^2+D_b^2\right)^2}\right)\left[V_j\cos(N_j-\psi_j) - V_o\cos(N_j-\psi_o)\right] +$$
$$-\lambda_5\frac{V_j\sin\psi_j - V_o\sin\psi_o}{D_j^2\cos N_j} - \dot{\lambda}_4 = 0.$$

4. For variable N_j^1 or $N_j^2: -\dot{\lambda}_5 = 0.$

5. For variable $\dot{\alpha}:\ \frac{\lambda_7}{T_{MS}} + \lambda_8\dot{\alpha}_{max} - 2\lambda_8\dot{\alpha} - \dot{\lambda}_7 = 0.$

6. For variable $\alpha: -\lambda_3 c_6 V_0^2 + \lambda_9(2\alpha+\alpha_{max}) + \lambda_{10}(2\alpha-\alpha_{max}) - \frac{\dot{\lambda}_7}{T_{MS}} + \dot{\lambda}_8\alpha_{max} - 2\dot{\alpha}\dot{\lambda}_8 = 0.$

7. For variable $\zeta_1:\ \lambda_8\zeta_1 = 0.$

8. For variable $\zeta_2:\ \lambda_9\zeta_2 = 0.$

9. For variable ζ_3: $\lambda_{10}\zeta_3 = 0.$
10. For variable ζ_5: $\lambda_{12}\zeta_5 = 0.$
11. For variable ζ_6: $\lambda_{13}\zeta_6 = 0.$
12. For variable u_α: $-\lambda_7 \frac{k_{MS}}{T_{MS}} + 2\lambda_{12}u_\alpha + \lambda_{12} + 2\lambda_{13}u_\alpha - \lambda_{13} = 0.$

The best way to solve the Euler-Lagrange equations is to start from equations (10), (11) which have alternative solutions:

$$\lambda_{12} = 0 \quad \text{or} \quad \zeta_5 = 0, \tag{12}$$

$$\lambda_{13} = 0 \quad \text{or} \quad \zeta_6 = 0. \tag{13}$$

The first solutions, in accordance with the Euler-Lagrange equations, lead to $\lambda_{12} = 0$ and $\lambda_{13} = 0$ which, due to arbitrariness of λ_{12} and λ_{13}, is excluded. At the same time this excludes the solution of $u_\alpha(t)$. But the second solutions gives two boundary values:

$$u_\alpha = 0 \text{ as well as } u_\alpha = -1 \text{ and } u_\alpha = 0 \text{ as well as } u_\alpha = 1. \tag{14}$$

Depending on the sign of the initial angular velocity of bearings change, this solution can be written as follows:

$$u_\alpha = sign \frac{dN_j^{1,2}}{dt} \tag{15}$$

Due to the fact that only the sign of angular velocity of bearing change is important, it is enough to treat (8) or (9) as the switching function $\delta(t)$:

$$\delta(t) = \left(\frac{1}{D_j} tgN_j \pm \frac{D_j D_b \sqrt{D_j}}{D_j^2 + D_b^2} \right) \left[n\cos(N_j - \psi_j) - \cos(N_j - \psi_o) \right] + \frac{n\sin\psi_j - \sin\psi_0}{D_j \cos N_j} \tag{16}$$

where D_j, N_j, ψ_0 can be derived from Eqs. (2), (8) and the coupling relations (4).

The solution of control in the general form can be written as follows:

$$u_\alpha = sign\delta(t)\left[H(t - t_0) - H(t - t_p) \right] \tag{17}$$

Dependence (17) contains two solutions $u_\alpha = sign\delta(t)$ for $t \in (t_0, t_p)$ and $u_\alpha = 0$ for $t \geq t_p$, but t_p corresponds to $\delta(t) = 0$. The change in direction of the ship motion requires a control impulse which can be calculated from (4), substituting control (16), and taking into account the technical limitations (3), as a result of which $t_p < \alpha / \dot{\alpha}_{\max}$ we obtain:

$$\alpha(t_p) - \alpha(t_0) = K_{MS}(t_p - t_0) sign\delta(t)\left[H(t - t_0) - H(t - t_p) \right] - T_{MS}\alpha_{\max}(t_p - t_0) \tag{18}$$

and for $t_p > \alpha / \dot{\alpha}_{\max}$:

$$\alpha(t_p) - \alpha(t_0) = \pm\alpha_{\max} \tag{19}$$

where $\alpha(t_p)$ is the angle of rudder blade deflection affecting the ship movement so as to achieve the parallel approaching the point of safe passing.

Ship's course ensuring parallel approaching can be calculated from (8) or (9), and the second and third equation from the set of equations (1). This way the duration time of control impulse executing time-optimum control is calculated.

4. THE SIMULATION STUDY

For the research purpose we use ship which parameters are as follow: displacement $V = 213{,}758[m^3]$, length on waterline $L = 36{,}3[m]$, width of the midship section $B = 7[m]$, draught $T = 1{,}742[m]$. The ship has two main propellers and two fin rudders which are situated in the shaft line.

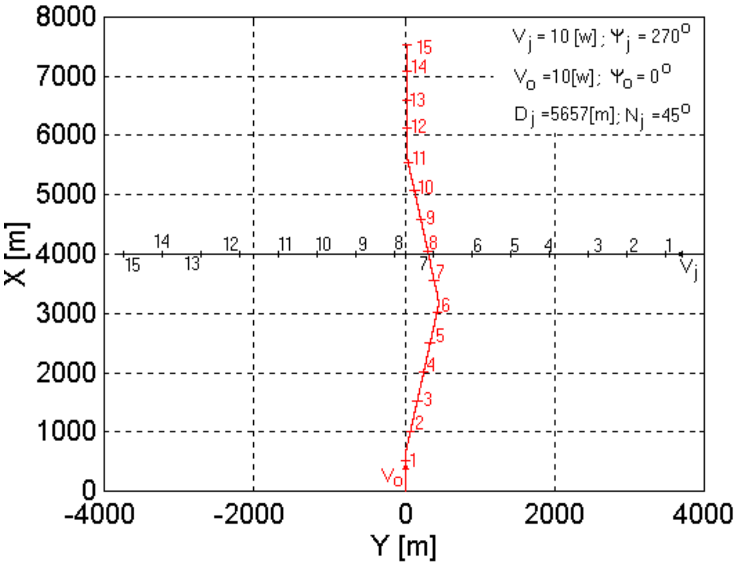

Figure 2 Trajectories of the encountered object and the own ship in collision situation at passing the encountered object behind its stern

A dangerous navigational situation was simulated for relative speed $\dot{D}_j < 0$ and velocity of change of the bearing angle $\dot{N}_j = 0$, i.e. for a critical case of parallel approach. The solution to the collision situation was searched for under the assumption that the encountered object does not make any maneuvers and is moving rectilinearly with a constant speed. For this situation the time-optimum control was calculated which determine the safe trajectory for the own ship. The research into controlling the ship movement was carried out by means of changing the course during the maneuver of safe passing behind the stern of the encountered object at a safe distance $D_b = 250[m]$. For this maneuver were calculated: the trajectories of the encountered object and the own ship, their state coordinates, control signals and solutions to the constraint equations. Results of the simulation research are presented in the figures below. The control signal and force acting on the rudder is calculated for time-optimum control.

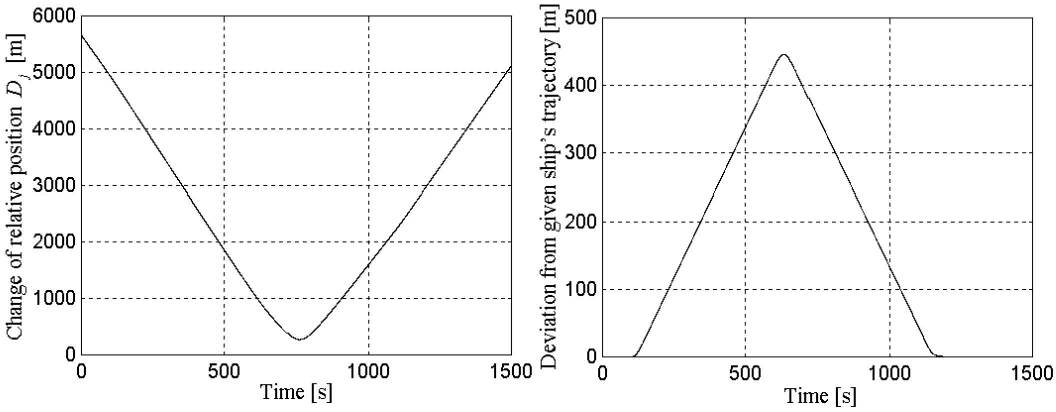

Figure 3 Change in relative position D_j and deviation from preset ship's trajectory during the collision avoidance maneuver

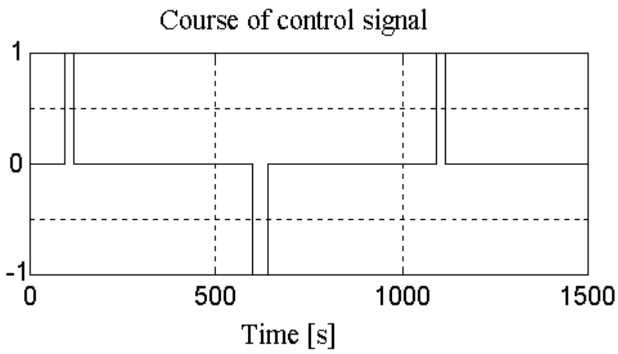

Figure 4 Distribution of control signal sent to the control unit

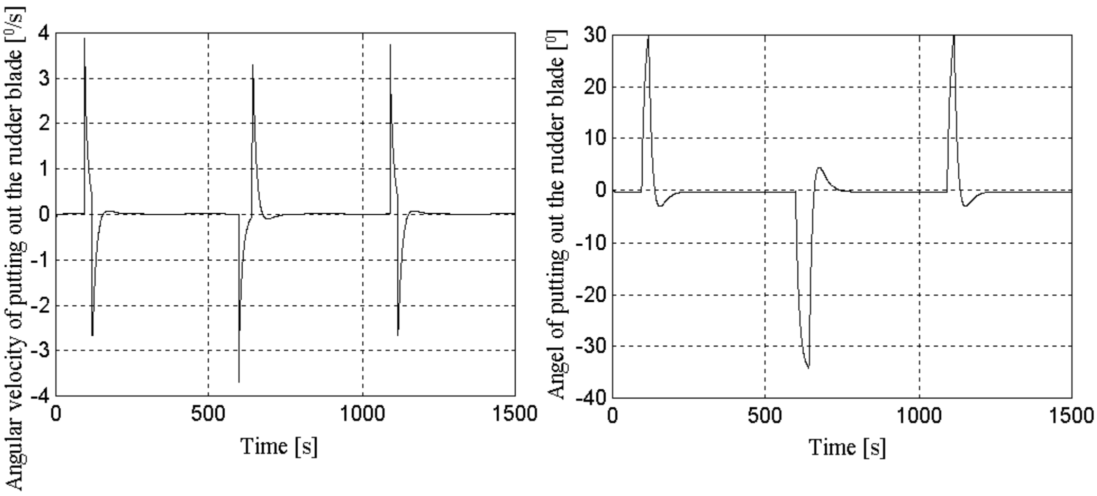

Figure 5 Angular velocity and angle of rudder blade deflection

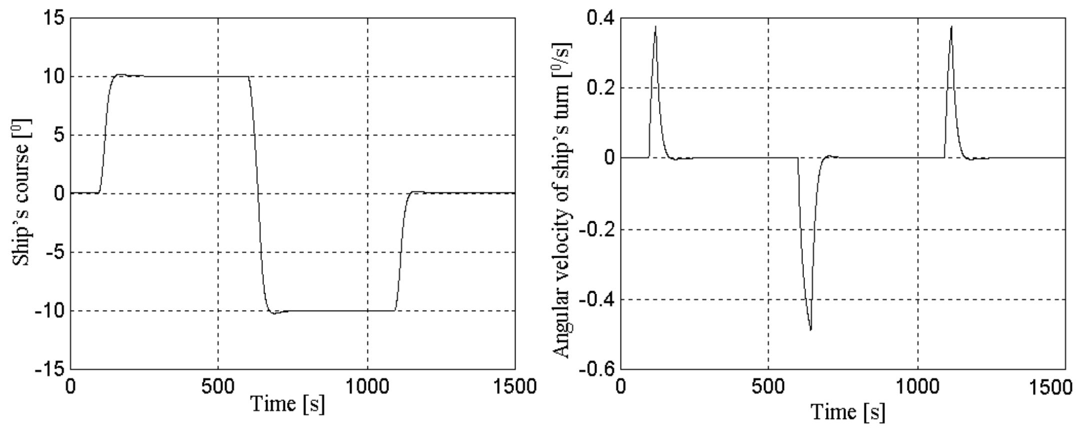

Figure 6 Course and angular speed of ship's turn during execution of collision avoidance maneuver

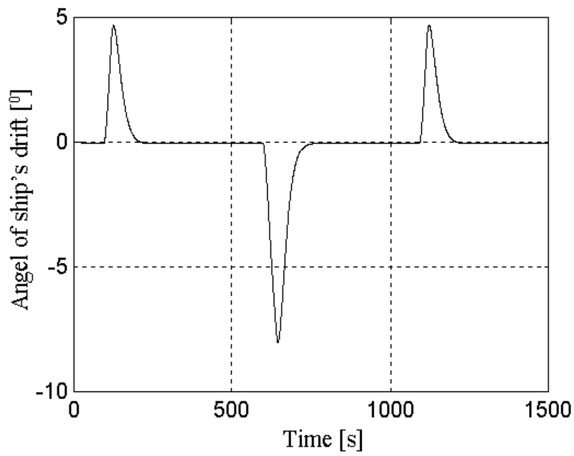

Figure 7 Angle of ship's drift

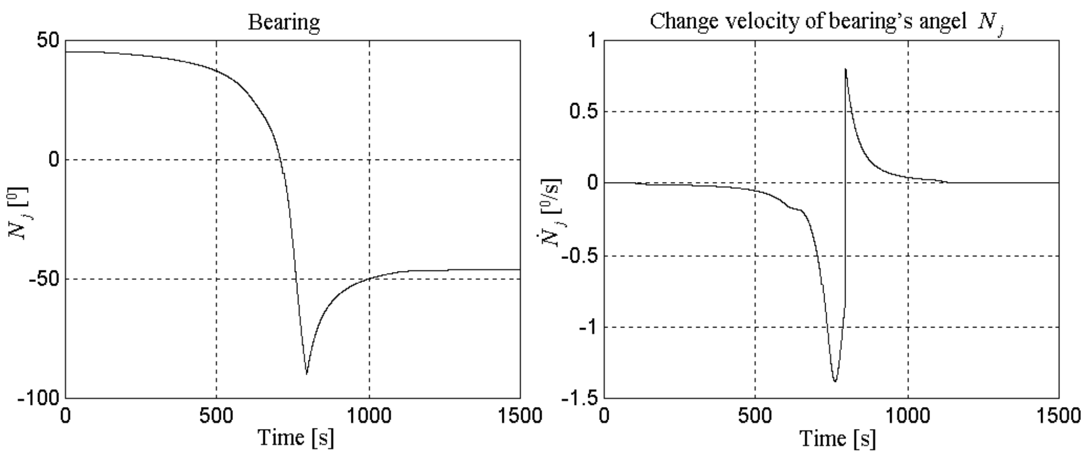

Figure 8 Changes of anticipated bearing and its derivative

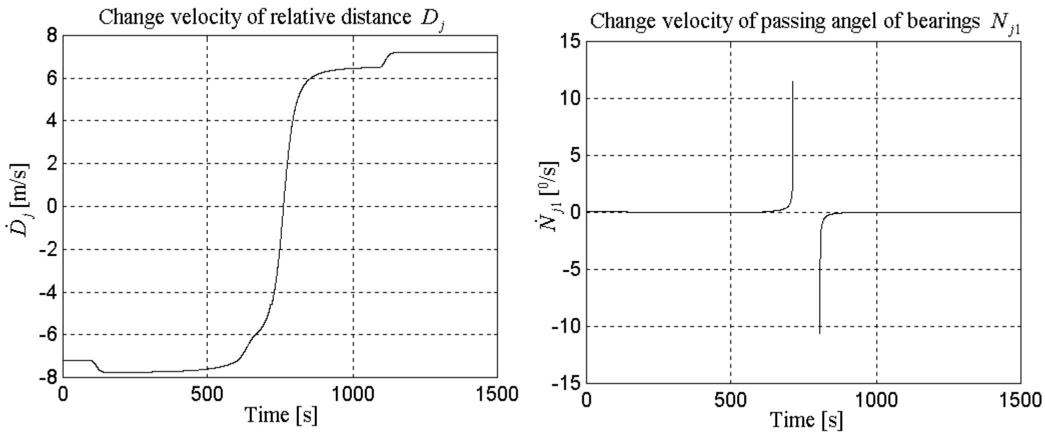

Figure 9 Derivatives of the distance and the anticipated angles of bearing

Figure 2 shows that in a simulated situation, own ship begins maneuver bypassing the encountered ship after its stern at a preset safe distance, while ensuring a minimum deviation from the given trajectory of movement. The change in the distance between ships and the distance from the given trajectory during the maneuver is presented on figure 3. The graphs shows that the shortest approaching distance will be reached after 748 [s], while the maximum deviation from the given trajectory will reach the value of 443 [m] after the time 626 [s]. The determined control signal transmitted to the steering machine during the anti-collision maneuver is shown on figure 4. It has a rectangular shape and ensures that the ship returns to the preset trajectory before the dangerous situation occurs. The response of the rudder blade to the given steering signal is shown on figure 5. Figures 6 and 7 shows the coordinates of the own ship's motion resulting from its dynamics, i.e. the ship's course, the angular velocity of the return and the angle of drift. Values of the presented parameters depends on the dynamics of the ship. Figures 8 and 9 shows the parameters describing the dynamics of the analyzed collision situation. The dynamics of changes in the value of the presented parameters depends on the parameters of the movement of ships in a collision situation. The values of these parameters increase as the distance between ships decreases and they are the highest when passing. The moment of intersection of the ship's trajectory results in a step change of the bearing derivative mark and the derivative of the anticipated bearing.

5. CONCLUSION

The solution of the problem of avoiding a collision at sea formulated as above is the time-optimum control of the own ship. The programs for time-optimum control have never been used in collision avoidance problems. In these problems, the parallel approach to an encountered object generates a dangerous situation, thus appropriate control has to be executed to avoid it. However, formulating the problem with constraint equations with respect to anticipated bearing angle $N_{j1,2}$ depending on safe distance of approach D_b, time-optimum control algorithm can be used to solve the collision situations at sea. The boundary process of time-optimum control, i.e. parallel approach, is possible only for such angles for which the condition of parallel approach is met as early as at time t_0. This obviously occurs when angular speed of the observation line is $\dot{N}_j = 0$. In the case of using the presented method to avoid a collision at a see and to calculate the time-optimum control, there is always a possibility of executing this control, since for the danger-posing object angular speed of the observation line is $\dot{N}_j = 0$, which means that parallel approach occurs. Then the task for controls is to obtain $\dot{N}_j \neq 0$ and to reduce to zero the speed of the anticipated observation line $N_{j1,2}$ at the moment of the switching the control, i.e. for $t = t_p$. At this moment both switching functions are resetting yourself. Further control is executed with the use of the controls $u_1 = 0, u_2 = 0$. It realizes the so-called parallel approaching with anticipated point, whose position is determined by the safe distance of passing D_b for given hydrodynamics and navigational conditions.

The time-optimum control has rectangular shape and belongs to the ideal control, whereas the time to lead the own ship to parallel approach with anticipated point depends mainly on maneuverability of the own ship, the initial value of angular speed of observation line and the value of safe distance of approach D_b.

From the presented research results it follows that the objects were approaching parallely, therefore they are critical cases where $\dot{N}_j = 0$ and $\dot{D}_j < 0$. After the collision avoidance maneuver, in accordance with the calculated time-optimum control, the angular speed of approach becomes different from zero ($\dot{N}_j \neq 0$), whereas the speed of anticipated observation line becomes zero ($\dot{N}_{j1,2} = 0$), thus there occurs the case where the own ship parallely approaches the anticipated point determined by value D_b. The trajectory which ensures passing the encountered object at a safe distance is achieved by the ship within a short time period because the executed maneuvers are weak, i.e. the change in course is performed within a small range.

At the moment when the encountered object has been passed, there is a change in speed sign of anticipated observation line $N_{j1,2}$ and in the speed of approaching D_j, and the encountered object becomes a safe object. At this time the control signal, brings the ship onto the preset trajectory. This signal has an opposite value to the signal calculated for the collision avoidance maneuver and its duration time is twice as long. Such signal causes the ship to turn and approach the preset trajectory along which it had been moving before the collision situation.

REFERENCES

[1] Dubiel S.: Guidance methods in navigation as an unfailing complex motion, (in Polish), IV National Conference "Automation of Navigation and Control Systems", s.17-27, Gdynia 1993.

[2] Dubiel S.: The imporatance of the principles of complex motion in problems concerning a controlled flight and navigation,(in Polish), National Conference "Automation of Navigation and Control Systems" s.47-62, Gdynia 1999.

[3] Fossen, T., Marine Control Systems: Guidance, Navigation and Control of Ships, Rigs and Underwater Vehicles. Marine Cybernetics AS Norwegian University of Science and Technology, Trondheim, 2002.

[4] Hadnett, E., A bridge too far?, Journal of Navigation, The Royal Institute of Navigation, Issue 61, 283-289, 2008.

[5] Kolendo, P., Śmierzchalski, R., Jaworski, B., 2011 a. Experimental research on evolutionary path planning algorithm with fitness function scaling for collision scenarios, Methods and Algorithms in Navigation: Marine Navigation and Saferty of Sea Transportation, CRC Press, vol 5, nr 4.

[6] Lisowski, J., Dynamic programming of safe ship trajectory with neural state constraints, Polish Journal of Environmental Studies, vol. 18, is. 4B, 2009.

[7] Lisowski J.: The sensitivity of state differential game vessel traffic model. Polish Maritime Research, vol. 23, is. 2, p. 14-18, 2016.

[8] Lisowski J., 2017, Game Control of maritime objects, Journal of Marine Engineering & Technology vol. 16 (4), 165-176.

[9] Lisowski J., 2018, Cooperative and non-cooperative game control strategies of the ship in collision situation, TransNav: International Journal on Marine Navigation and Safety of Sea Transportation t.12.

[10] Padfield P.: *A nightmare of collisions, Maritime Publishing*, Gdańsk 1969.

[11] Pietrzykowski, Z., Navigational Decision Support System on the Sea Ship, (in Polish), Scientific Publisher of the Maritime University of Szczecin, 2011.

[12] Śmierzchalski, R., Kuczkowski, Ł., Kolendo, P., Jaworski, B., Distributed Evolutionary Algorithm for Path Planning in Navigation Situation, TransNav: the International Journal on Marine Navigation and Safety of Sea Transportation, vol. 7, nr 2, 2013.

[13] Śmierzchalski, R., Kolendo, P., Kuczkowski, Ł., Jaworski, B., Witkowska, A., The Niching Mechanism in the Evolutionary Method of Path Planning, Lectures Notes in Computer Science: Artificial Intelligence and Soft Computing, LNAI 7895, 101-112, 2013.

[14] Szłapczyński, R., Evolutionary Sets of Safe Ship Trajectories within Traffic Separation Schemes, Journal of Navigation, vol. 66. 2012

[15] Żak B., Selected problems of synthesis of the anti-collision system of the ship's motion control. Publisher of the Polish Naval Academy, No 146B s. 174, Gdynia, 2001.

DESCRIPTION OF THE DYNAMIC CHARACTERISTIC OF THE FLOATING OBJECTS BY MEANS OF THE SMOOTHING SPLINES

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Summary

There are described some dynamic characteristic of the floating objects by means of the smoothing polynomial splines of third order in that work. The elaborated algorithm was used to approximate the process of changes of the trim angle of a submarine due to water displacement in the trim containers from the stern to the bow.

Keywords: smoothing splines, identification, interpolation, approximation

1. INTRODUCTION

The rapid development of technical progress enables the optimal control of floating objects. Most floating objects can be treated as dynamic systems. Intuitively, a dynamic system is an object considered from the point of view of its behavior in time. Using the laws of physics one can determine the mathematical model of a real floating object in the form of differential equations with unknown coefficients. However the coefficients of these equations can be determined on the basis on the measurement data of input and output signals. The process of activities the result of which is building a mathematical model recognized - in accordance with the adopted assessment criterion - as sufficiently well describing the behavior of a real floating object, is called the identification system. The floating object identification system includes:

a) a description of the input and output quantities
b) mathematical model of the relationship between input and output signals
c) the verification of a model.

Correctly built mathematical model of the real floating object obtained as a result of identification makes it possible to determine the control algorithm as well as to design devices implementing the control algorithm. Despite many works devoted to the identification of dynamic systems, new methods of identification systems convenient for electronic computing are still needed. The accuracy of identification is strongly influenced by the choice of functions describing the input and output quantities. The purpose of the work is to present a method of signal description in the form of smoothing third-degree splines. Classical methods of solving the problem of interpolation rely on building Lagrange interpolation polynomial. The Lagrange interpolation sequence of polynomials needs not converge to the interpolation function. The interpolation polynomial sketching may differ significantly from the curve of the interpolated function, especially at the ends of the interpolation interval. Similar problems occur with the approximation of function by means of polynomials. For example in the case of the frequently used mean square approximation, the problem of determining polynomials approximating higher degrees (greater than 5) is badly conditioned which can cause serious calculation perturbations on digital machines.

2. SPLINES

Dependencies between the physical quantities are usually described by functions whose exact forms we do not know [2], [7]. Information about the given function $y = f(x),\ x \in [a, b]$ often consists of the values of functions $y_k,\ k = 0,1,\dots,N$ or its derivatives in points x_k , $k = 0,1,\dots, N$, whereby

$$a = x_0 < x_1 <\dots< x_{N-1} < x_N = b.$$

The points $x_k,\ k = 0,1,\dots,N$, determine a certain division of the interval $[a, b]$ into N subintervals. Let us denote the division as Δ_N. The points x_k are called function knots.

From the physical properties we can approximate the nature of a function f belonging to a certain class of function Φ; for example, that it is a polynomial of a low order, exponential function, periodic function, etc.

The interpolation task at given $N + 1$ pairs of numbers $(x_k, y_k),\ k = 0,1,\dots,N$ consists in determining in the set function class of functions Φ the function g approximating the function f for which the functions g and f values in the knots are equal. In practical issues we deal with quantities $\tilde{y}_k$ that are values of an interpolated function, burdened with certain errors. In this case, it makes no sense to construct an interpolation function having values $\tilde{y}_k$ .in points x_k.

Next, we will give an algorithm for the determination of the smoothing function in the class of natural polynomial splines of first and third order of which in the process in the surrounding of the points x_k is more fluid than the interpolative function.

Definition 1 The function $s = s(x, \Delta_N)$ defined on $[a, b]$ is called the spline of m $(m \geq 1)$ order with the knots

Δ_N: $\quad a = x_0 <\dots< x_N = b$ if :

(a) on every subinterval $[x_{k-1}, x_k]$, $k \in \overline{1, N}$, s is a polynomial of the order m and lower,
(b) s is a function of $C^{m-1}([a, b])$ class, i.e. it is a continuous function in $[a, b]$ together with its derivatives of the first and second order.

The set of all the splines of the m order with the knots Δ_N is denoted as $S_m(\Delta_N)$.

The spline of m order consists of the polynomials of m -th order joined together in a such way that their values and the values of their $m - 1$ derivatives are equal in the knots $x_k,\ k = 1,\dots,N - 1$.

Next we will deal with the splines interpolating the given points (x_k, y_k), $k = 0,1, \dots, N$.

Let $(x) \in C_{[a,b]}$, where $C_{[a,b]}$ denotes the class of the continuous functions defined in $[a, b]$.

Definition 2 The function s is called the interpolating spline function of the m order for the function $y = f(x)$ if

$$s(t_k) = f(t_k) = y_k, \quad k \in \overline{0, N},\ N \geq 2.$$

The searched function s will be presented as follows

$$s(x) = \begin{cases} W_1(x) & \text{for} & [x_0, x_1) \\ \cdots & \cdots & \cdots \\ W_k(x) & \text{for} & [x_{k-1}, x_k) \\ \cdots & \cdots & \cdots \\ W_N(x) & \text{for} & [x_{N-1}, x_N) \end{cases},$$

where:

$$W_k(t) = \alpha_{k0} + \alpha_{k1}(x - x_{k-1}) + \alpha_{k2}(x - x_{k-1})^2 + \dots + d_{km}(x - x_{k-1})^m.$$

The function depends on $N(m+1)$ constants α_{kv}, $v = 0,1,\dots,m$. From the definition of the interpolating spline function and from request of its continuity together with its derivatives of $1,2,\dots,m-1$ order, in each internal knot $x_1, x_2, \dots, x_{N-1}$, there are $N+1+m(N-1)$ conditions. Therefore the interpolating spline function s depends on $N(m+1)-(N+1+m(N-1)) = m-1$ parameters that is why we superpose on them $m-1$ additional conditions. The choice of those conditions depends both on the properties of $y = f(x)$ and given information about the function.

3. NATURAL SMOOTHING SPLINES OF THIRD ORDER

Definition 3 The spline of third order with the knots (Δ_N) is called the natural spline function if it is a linear function in the intervals $(-\infty, a)$ and (b, ∞) [2], [7].

The natural spline function s satisfies the initial conditions

$$s''(a) = s''(b) = 0. \tag{1}$$

In every interval $[x_{k-1}, x_k]$, $k = 0,1,\dots,N+1$ ($x_{-1} := -\infty$, $x_{N+1} := +\infty$) the natural spline function of the third order can be presented in the following form:

$$s(x) = \begin{cases} W_0(x) & \text{for} \quad x \in (-\infty, x_0) \\ W_1(x) & \text{for} \quad x \in [x_0, x_1] \\ \cdots & \cdots \quad \cdots \\ W_k(x) & \text{for} \quad x \in [x_{k-1}, x_k] \\ \cdots & \cdots \quad \cdots \\ W_N(x) & \text{for} \quad x \in [x_{N-1}, x_N] \\ W_{N+1}(x) & \text{for} \quad x \in [x_N, \infty) \end{cases}, \tag{2}$$

where

$$W_0(x) = a_0 + b_0 x$$

$$W_k(t) = a_k + b_k(x - x_{k-1}) + c_k(x - x_{k-1})^2 + d_k(x - x_{k-1})^3$$

$$W_{N+1}(x) = a_{N+1} + b_{N+1}(x - x_N).$$

Let us denote

$$y_k = s(x_k), \qquad m_k = s''(x_k), \tag{3}$$

and

$$\widetilde{\boldsymbol{Y}} = \begin{bmatrix} \tilde{y}_0 \\ \vdots \\ \tilde{y}_N \end{bmatrix}, \quad \boldsymbol{Y} = \begin{bmatrix} y_0 \\ \vdots \\ y_N \end{bmatrix}, \quad \boldsymbol{M} = \begin{bmatrix} m_0 \\ \vdots \\ m_N \end{bmatrix}.$$

Next we require that the unknown spline function s minimalize the functional

$$J(s) = \sum_{k=0}^{N} \frac{1}{\rho_k}[y_k - \tilde{y}_k]^2 dx + \kappa \int_{x_0}^{x_N} [s''(x)]^2 dx, \tag{4}$$

where $\kappa \geq 0, \rho_k > 0$, $k = 0,1,\dots,N$ are given numbers.

That functional is a kind of compromise between fitting to the measurements, about which the first part of it decides and possibly smallest function variability ('arcuation', 'smoothness) about which the second part of the functional decides. The smaller weight values of the coefficients ρ_k are the closer to the given points $\tilde{y}_k$ the function s is situated. On the other hand the increase of the weight coefficient κ decreases the oscillations of the constructed function s, but at the cost of its run distance from the given points $\tilde{y}_k$, $k = 0,1,\dots,N$.

We will denote the function s which minimalize the functional (4) by $\hat{y}$ and call it the natural smoothing spline of third order.

As the natural spline is uniquely determined by its values $y_k,\ k = 0,1,\dots,N$ the problem of minimalizing the functional (4) is introduced to the task of determining the minimum of a function of $N+1$ variables $y_0, y_1, \dots, y_N$. According to definition of the spline of third order, the derivative $s'''(x)$ is continuous in $[a,b]$ and linear on every subinterval and it passes through the points (x_{k-1}, m_{k-1}), (x_k, m_k). Therefore $s''(x)$ can be presented as

$$s''(x) = \frac{m_k - m_{k-1}}{x_k - x_{k-1}}(x - x_{k-1}) + m_{k-1}, \quad x \in [x_{k-1}, x_k]$$

on every subinterval $[x_{k-1}, x_k]$, $\quad k = 1,2,\dots,N$.

Hence

$$s''(x) = m_{k-1}\frac{x_k - x}{h_k} + m_k\frac{x - x_{k-1}}{h_k}, \quad x \in [x_{k-1}, x_k], \quad h_k := x_k - x_{k-1}. \tag{5}$$

Integrating twice both sides of (5) we obtain

$$s'(x) = -m_{k-1}\frac{(x_k - x)^2}{2h_k} + m_k\frac{(x - x_{k-1})^2}{2h_k} + A_k$$

$$s(x) = m_{k-1}\frac{(x_k - x)^3}{6h_k} + m_k\frac{(x - x_{k-1})^3}{6h_k} + A_k x + B_k, \tag{6}$$

where $A_k,\ B_k$ are constants.

From the interpolation conditions $s(x_k) = y_k,\ k = 0,1,\dots,N$ we get the system of equations

$$s(x_{k-1}) = m_{k-1}\frac{h_k^2}{6} + B_k = y_{k-1}$$

$$s(x_k) = m_k\frac{h_k^2}{6} + A_k h_k + B_k = y_k.$$

From the above equalities we obtain

$$A_k = \frac{y_k - y_{k-1}}{h_k} - \frac{h_k}{6}(m_k - m_{k-1})$$

$$B_k = y_{k-1} - m_{k-1}\frac{h_k^2}{6} - A_k x_{k-1}. \tag{7}$$

Substituting A_k, B_k in (6), finally after some transformations we have

$$s(x) = m_{k-1}\frac{(x_k - x)^3}{6h_k} + m_k\frac{(x - x_{k-1})^3}{6h_k} + (y_{k-1} - \frac{m_{k-1}h_k^2}{6})\frac{x_k - x}{h_k}x + \dots + (y_k - \frac{m_k h_k^2}{6})\frac{x - x_{k-1}}{h_k}$$

$$s'(x) = -m_{k-1}\frac{(x_k - x)^2}{2h_k} + m_k\frac{(x - x_{k-1})^2}{2h_k} + \frac{y_k - y_{k-1}}{h_k} - \frac{m_k - m_{k-1}}{6}h_k\ . \tag{8}$$

As we see the spline s is characterized by its moments m_k. Now we are going to determine those moments.

According to the definition of the determined spline s, the derivatives of it: s', s'' are also continuous functions in $[a,b]$.

Assuming of the continuity of s' in the knots $x_1, x_2, \dots, x_{N-1}$, i.e. $s'(x_k^-) = s'(x_k^+)$ determines $N-1$ equations for the moments m_k.

From (8) we are going to determine one-sided limits of derivative of s in the points $x_1, x_2, \dots, x_{N-1}$:

$$s'(x_k^-) = \frac{h_k}{6}m_{k-1} + \frac{h_k}{3}m_k + \frac{y_k - y_{k-1}}{h_k}$$

$$s'(x_k^+) = -\frac{h_{k+1}}{3}m_k - \frac{h_{k+1}}{6}m_{k+1} + \frac{y_{k+1} - y_k}{h_{k+1}}.$$

As $s'(x_k^-) = s'(x_k^+)$ for $k = 1,2,\dots,N-1$ we obtain the equations

$$\frac{h_k}{6}m_{k-1} + \frac{h_k + h_{k+1}}{3}m_k + \frac{h_{k+1}}{6}m_{k+1} = \frac{y_{k+1} - y_k}{h_{k+1}} - \frac{y_k - y_{k-1}}{h_k}, \quad k = 1,2,\dots,N-1$$

There are $N-1$ equations for $N+1$ moments.

We add two additional equations: $m_0 = 0, m_N = 0$ following from the properties of the natural spline function. Substituting m_0, m_N we obtain the system of algebraic linear equations

$$\begin{cases} \frac{h_1 + h_2}{3}m_1 + \frac{h_2}{6}m_2 = \frac{y_2 - y_1}{h_2} - \frac{y_1 - y_0}{h_1} \\ \frac{h_2}{6}m_1 + \frac{h_2 + h_3}{3}m_2 + \frac{h_3}{6}m_3 = \frac{y_3 - y_2}{h_{k+1}} - \frac{y_2 - y_1}{h_2}, \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ \frac{h_{N-1}}{6}m_{N-2} + \frac{h_{N-1} + h_N}{3}m_{N-1} = \frac{y_N - y_{N-1}}{h_N} - \frac{y_{N-1} - y_{N-2}}{h_{N-1}} \end{cases}$$

for the unknowns $m_1, m_2, \dots, m_{N-1}$.

Those equations can be rewritten in the form:

$$\begin{cases} 2(h_1 + h_2)m_1 + h_2 m_2 = 6(\frac{1}{h_1}y_0 - (\frac{1}{h_1} + \frac{1}{h_2})y_1 + \frac{1}{h_2}y_2) \\ h_2 m_1 + 2(h_2 + h_3)m_2 + h_3 m_3 = 6(\frac{1}{h_2}y_1 - (\frac{1}{h_2} + \frac{1}{h_3})y_2 + \frac{1}{h_3}y_3) \\ \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \\ h_{N-1}m_{N-2} + 2(h_{N-1} + h_N)m_{N-1} = 6(\frac{1}{h_{N-1}}y_{N-2} - (\frac{1}{h_{N-1} + h_N})y_{N-1} + \frac{1}{h_N}y_N \end{cases}$$

Now the system of equation we show in matrix form

$$\boldsymbol{AM} = \boldsymbol{6HY} \tag{9}$$

where

$$\boldsymbol{A} = \begin{bmatrix} 2(h_1 + h_2) & h_2 & 0 & \cdots & \cdots & \cdots & \cdots & 0 \\ h_2 & 2(h_2 + h_3) & h_3 & 0 & \cdots & \cdots & \cdots & 0 \\ 0 & h_3 & 2(h_3 + h_4) & h_4 & 0 & \cdots & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & \cdots & \cdots & \cdots & \cdots & 0 & h_{N-1} & 2(h_{N-1} + h_N) \end{bmatrix},$$

$$\boldsymbol{H} = \begin{bmatrix} \frac{1}{h_1} & -(\frac{1}{h_1} + \frac{1}{h_2}) & \frac{1}{h_2} & 0 & \cdots & \cdots & \cdots & 0 \\ 0 & \frac{1}{h_2} & -(\frac{1}{h_2} + \frac{1}{h_3}) & \frac{1}{h_3} & 0 & \cdots & \cdots & 0 \\ 0 & 0 & \frac{1}{h_3} & -(\frac{1}{h_3} + \frac{1}{h_4}) & \frac{1}{h_4} & 0 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & \cdots & \cdots & \cdots & 0 & \frac{1}{h_{N-1}} & -(\frac{1}{h_{N-1}} + \frac{1}{h_N}) & \frac{1}{h_N} \end{bmatrix},$$

$$\boldsymbol{M} = \begin{bmatrix} m_1 \\ m_2 \\ \vdots \\ m_{N-1} \end{bmatrix}, \quad \boldsymbol{Y} = \begin{bmatrix} y_0 \\ y_1 \\ \vdots \\ y_N \end{bmatrix}.$$

After substituting (5) in $s''(x)$ the functional (4) takes the form of

$$J(y_0, \dots, y_N) = \sum_{k=0}^{N} \frac{1}{\rho_k}[y_k - \tilde{y}_k]^2 dx + \kappa \sum_{k=1}^{N} \int_{x_{k-1}}^{x_k} [m_{k-1}\frac{x_k - x}{h_k} + m_k \frac{x - x_{k-1}}{h_k}]^2 dx \tag{10}$$

Next integrating in (10) we have some dependences

$$\sum_{k=1}^{N}\int_{x_{k-1}}^{x_k}[m_{k-1}\frac{x_k-x}{h_k}+m_k\frac{x-x_{k-1}}{h_k}]^2dx=\sum_{k=1}^{N}[\frac{1}{3}m_{k-1}^2h_k+\frac{1}{3}m_{k-1}m_kh_k+\frac{1}{3}m_k^2h_k]=$$

$$=\frac{1}{3}m_1^2h_1+\frac{1}{3}m_1^2h_2+\frac{1}{3}m_1m_2h_2+\frac{1}{3}m_2^2h_2+\frac{1}{3}m_2^2h_3+\frac{1}{3}m_2m_3h_3+\frac{1}{3}m_3^2h_3+$$
$$+\cdots+\frac{1}{3}m_{N-2}^2h_{N-1}+\frac{1}{3}m_{N-2}m_{N-1}h_{N-1}+\frac{1}{3}m_{N-1}^2h_{N-1}+\frac{1}{3}m_{N-1}^2h_N+\frac{1}{3}m_{N-1}m_Nh_N=$$
$$=\frac{1}{3}m_1^2h_1+\frac{1}{3}m_1^2h_2+\frac{1}{6}m_1m_2h_2+\frac{1}{6}m_1m_2h_2+\frac{1}{3}m_2^2h_2+\frac{1}{3}m_2^2h_3+\frac{1}{6}m_2m_3h_3+$$
$$+\frac{1}{6}m_2m_3h_3+\frac{1}{3}m_3^2h_3+\frac{1}{3}m_3^2h_4+\frac{1}{6}m_3m_4h_4++\frac{1}{6}m_3m_4h_4+\frac{1}{3}m_4^2h_4+\cdots+$$
$$+\frac{1}{6}m_{N-3}m_{N-2}h_{N-2}+\frac{1}{3}m_{N-2}^2h_{N-2}+\frac{1}{3}m_{N-2}^2h_{N-1}+\frac{1}{6}m_{N-2}m_{N-1}h_{N-1}+$$
$$+\frac{1}{6}m_{N-2}m_{N-1}h_{N-1}+\frac{1}{3}m_{N-1}^2h_{N-1}+\frac{1}{3}m_{N-1}^2h_N= \tag{11}$$
$$=m_1(\frac{h_1+h_2}{3}m_1+\frac{h_2}{6}m_2)++m_2(\frac{h_2}{6}m_1+\frac{h_2+h_3}{3}m_2+\frac{h_3}{6}m_3)+$$
$$+m_3(\frac{h_3}{6}m_2+\frac{h_3+h_4}{3}m_3+\frac{h_4}{6}m_4)+\cdots+m_{N-2}(\frac{h_{N-2}}{6}m_{N-3}+\frac{h_{N-2}+h_{N-1}}{3}m_{N-2}+\frac{h_{N-1}}{6}m_{N-1})$$
$$+m_{N-1}(\frac{h_{N-1}}{6}m_{N-2}+\frac{h_{N-1}+h_N}{3}m_{N-1})=\frac{1}{6}\boldsymbol{M^TAM}$$

Taking into consideration (3) and (11) we notice that the functional (10) can be written as

$$J(\boldsymbol{M})=[\boldsymbol{Y}-\widetilde{\boldsymbol{Y}}]^{\boldsymbol{T}}\boldsymbol{R^{-1}}[\boldsymbol{Y}-\widetilde{\boldsymbol{Y}}]+\kappa\frac{1}{6}\boldsymbol{M^TAM}, \tag{12}$$

where

$$\boldsymbol{R}=\begin{bmatrix}\rho & 0 & \cdots & \cdots & 0\\ 0 & \rho & 0 & \cdots & 0\\ \cdots & \cdots & \cdots & \cdots & \cdots\\ 0 & \cdots & \cdots & 0 & \rho\end{bmatrix}.$$

From (9) we get

$$\boldsymbol{M}=6\boldsymbol{A}^{-1}\boldsymbol{HY} \tag{13}$$

Therefore the functional (13) can be presented in the following form

$$J(Y)=[\boldsymbol{Y}-\widetilde{\boldsymbol{Y}}]^{\boldsymbol{T}}\boldsymbol{R^{-1}}[\boldsymbol{Y}-\widetilde{\boldsymbol{Y}}]+\kappa\frac{1}{6}(6\boldsymbol{A}^{-1}\boldsymbol{HY})^{\boldsymbol{T}}6\boldsymbol{HY}$$

that is

$$J(Y)=[\boldsymbol{Y}-\widetilde{\boldsymbol{Y}}]^{\boldsymbol{T}}\boldsymbol{R^{-1}}[\boldsymbol{Y}-\widetilde{\boldsymbol{Y}}]+6\kappa\boldsymbol{Y^T}\boldsymbol{H}^T(\boldsymbol{A^{-1}})^{\boldsymbol{T}}\boldsymbol{HY}\ . \tag{14}$$

Now $J(\mathbf{Y})$ takes the form of

$$J(Y)=[\boldsymbol{Y}-\widetilde{\boldsymbol{Y}}]^{\boldsymbol{T}}\boldsymbol{R^{-1}}[\boldsymbol{Y}-\widetilde{\boldsymbol{Y}}]+6\kappa\boldsymbol{Y^T}\boldsymbol{H}^T\boldsymbol{A^{-1}}\boldsymbol{HY}.$$

Now we are going to denote the function s minimalizing the functional (4) as $\hat{y}_i$ and call it natural smoothing spline of third order.

The problem of choice the spline $\hat{y}$ minimalizing the functional $J(s)$ is carried to determine the vector $\widehat{\boldsymbol{Y}}=[\hat{y}_0,\hat{y}_1,\dots,\hat{y}_N]^T$ which minimalizes $J(\mathbf{Y})$.

So our task now is to find such system $(\hat{y}_0,\hat{y}_1,\dots,\hat{y}_N)$ of real numbers that

$$J(\hat{y}_0,\hat{y}_1,\dots,\hat{y}_N)=\min\{J(y_0,y_1,\dots,y_N):\quad y_i\in\boldsymbol{R}\}.$$

The functional (14) is a positively defined form and its only extreme value is minimum while the point $\widehat{\boldsymbol{Y}}$ in which this extreme value is achieved can be determined from the dependence

$$\frac{\partial J}{\partial Y}=\mathbf{0}.$$

Next using the property that $\frac{\partial \boldsymbol{x}^T \boldsymbol{A}\boldsymbol{x}}{\partial \boldsymbol{x}} = 2\boldsymbol{A}\boldsymbol{x}$ [4], where $\boldsymbol{x}$ is a one column vector and $\boldsymbol{A}$ is a symmetric matrix we obtain

$$\frac{\partial \boldsymbol{J}}{\partial \boldsymbol{Y}} = 2\boldsymbol{R}^{-1}[\widehat{\boldsymbol{Y}} - \widetilde{\boldsymbol{Y}}] + 12\kappa \boldsymbol{H}^T \boldsymbol{A}^{-1}\boldsymbol{H}\widehat{\boldsymbol{Y}} = 0.$$

Hence

$$\boldsymbol{R}^{-1}[\widehat{\boldsymbol{Y}} - \widetilde{\boldsymbol{Y}}] + 6\kappa \boldsymbol{H}^T \boldsymbol{A}^{-1}\boldsymbol{H}\widehat{\boldsymbol{Y}} = \boldsymbol{0}.$$

Then the condition allowing to determine the minimum of the functional (4) we are able to obtain in the following form

$$\widehat{\boldsymbol{Y}} + 6\kappa \boldsymbol{R}\boldsymbol{H}^T \boldsymbol{A}^{-1}\boldsymbol{H}\widehat{\boldsymbol{Y}} = \widetilde{\boldsymbol{Y}}. \tag{15}$$

Having regard to $\boldsymbol{A}\boldsymbol{M} = 6\boldsymbol{H}\widehat{\boldsymbol{Y}}$, we get the equation

$$\widehat{\boldsymbol{Y}} + \kappa \boldsymbol{R}\boldsymbol{H}^T \boldsymbol{M} = \widetilde{\boldsymbol{Y}}. \tag{16}$$

Multiplying left sided of (15) by $\boldsymbol{H}$ we get

$$\boldsymbol{H}\widehat{\boldsymbol{Y}} + 6\kappa \boldsymbol{H}\boldsymbol{R}\boldsymbol{H}^T \boldsymbol{A}^{-1}\boldsymbol{H}\widehat{\boldsymbol{Y}} = \boldsymbol{H}\widetilde{\boldsymbol{Y}}$$

Considering $\boldsymbol{A}\boldsymbol{M} = 6\boldsymbol{H}\widehat{\boldsymbol{Y}}$ we have

$$\boldsymbol{A}\boldsymbol{M} + 6\kappa \boldsymbol{H}\boldsymbol{R}\boldsymbol{H}^T \boldsymbol{A}^{-1}\boldsymbol{A}\boldsymbol{M} = 6\boldsymbol{H}\widetilde{\boldsymbol{Y}}$$

That is why

$$(\boldsymbol{A} + 6\kappa \boldsymbol{H}\boldsymbol{R}\boldsymbol{H}^T)\boldsymbol{M} = 6\boldsymbol{H}\widetilde{\boldsymbol{Y}}. \tag{17}$$

The matrix $\boldsymbol{A} + 6\kappa \boldsymbol{H}\boldsymbol{R}\boldsymbol{H}^T$ of the above system is a penta-diagonal, symmetric and positively defined matrix.

Next after denoting

$$\boldsymbol{B} = \boldsymbol{A} + 6\kappa \boldsymbol{H}\boldsymbol{R}\boldsymbol{H}^T, \quad \boldsymbol{G} = 6\boldsymbol{H}\widetilde{\boldsymbol{Y}},$$

it is more convenient to write the system of equations (17) as

$$\boldsymbol{B}\boldsymbol{M} = \boldsymbol{G}, \tag{18}$$

where

$$\boldsymbol{B} = \begin{bmatrix} \lambda_1 & \vartheta_1 & \eta_1 & 0 & 0 & \cdots & \cdots & \cdots & 0 \\ \vartheta_1 & \lambda_2 & \vartheta_2 & \eta_2 & 0 & \ddots & \ddots & \ddots & 0 \\ \eta_1 & \vartheta_2 & \lambda_3 & \vartheta_3 & \eta_3 & 0 & \ddots & \ddots & 0 \\ 0 & \eta_2 & \vartheta_3 & \lambda_4 & \vartheta_4 & \eta_4 & 0 & \ddots & 0 \\ \cdots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \cdots \\ 0 & \ddots & \ddots & \eta_{i-2} & \vartheta_{i-1} & \lambda_i & \vartheta_i & \eta_i & 0 \\ \cdots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \cdots \\ 0 & \ddots & \ddots & \ddots & 0 & \eta_{N-4} & \vartheta_{N-3} & \lambda_{N-2} & \vartheta_{N-2} \\ 0 & \cdots & \cdots & \cdots & \cdots & 0 & \eta_{N-3} & \vartheta_{N-2} & \lambda_{N-1} \end{bmatrix}, \quad \boldsymbol{G} = \begin{bmatrix} g_1 \\ g_2 \\ g_3 \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ g_{N-1} \end{bmatrix}.$$

The coefficients of the system of equations are expressed by formulae:

$$\lambda_k = \frac{1}{3}(h_k + h_{k+1}) + \kappa \left(\frac{1}{h_k^2}\rho_{k-1} + \left(\frac{1}{h_k} + \frac{1}{h_{k+1}}\right)^2 \rho_k + \frac{1}{h_{k+1}^2}\rho_{k+1}\right), \quad k = 1, \dots, N-1,$$

$$\vartheta_k = \frac{1}{6}h_{ki+1} - \frac{\kappa}{h_{k+1}}\left[\left(\frac{1}{h_k} + \frac{1}{h_{k+1}}\right)\rho_k + \left(\frac{1}{h_{k+1}} + \frac{1}{h_{k+2}}\right)\rho_{k+1}\right], \quad k = 1, \dots, N-2, \tag{19}$$

$$\eta_k = \frac{\kappa}{h_{k+1}h_{k+2}}\rho_k, \quad k = 1, \dots, N-3, \quad g_k = \frac{1}{h_k}y_{k-1} - \left(\frac{1}{h_k} + \frac{1}{h_{k+1}}\right)y_k + \frac{1}{h_{k+1}}y_{k+1},$$

$k = 1, \dots, N-1.$

As the matrix $\boldsymbol{B}$ is symmetric then there exists the unique distribution

$$\boldsymbol{B} = \boldsymbol{UWU^T}, \tag{20}$$

where $\boldsymbol{U}$ and $\boldsymbol{W}$ have the forms correspondingly:

$$\boldsymbol{W} = \begin{bmatrix} w_1 & 0 & \cdots & \cdots & 0 \\ 0 & w_2 & 0 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & \cdots & \cdots & 0 & w_{N-1} \end{bmatrix},$$

$$\boldsymbol{U} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & 0 \\ p_1 & 1 & 0 & 0 & 0 & \ddots & \ddots & \ddots & 0 \\ q_1 & p_2 & 1 & 0 & 0 & 0 & \ddots & \ddots & 0 \\ 0 & q_2 & p_3 & 1 & 0 & 0 & 0 & \ddots & 0 \\ \cdots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \cdots \\ 0 & \ddots & \ddots & q_{i-2} & p_{i-1} & 1 & 0 & 0 & 0 \\ \cdots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \cdots \\ 0 & \ddots & \ddots & \ddots & 0 & q_{N-4} & p_{N-3} & 1 & 0 \\ 0 & \cdots & \cdots & \cdots & \cdots & 0 & q_{N-3} & p_{N-2} & 1 \end{bmatrix},$$

$$\boldsymbol{U}^T = \begin{bmatrix} 1 & p_1 & q_1 & 0 & 0 & \cdots & \cdots & \cdots & 0 \\ 0 & 1 & 0 & 0 & 0 & \ddots & \ddots & \ddots & 0 \\ 0 & 0 & 1 & p_2 & q_2 & 0 & \ddots & \ddots & 0 \\ 0 & \ddots & 0 & 1 & p_3 & q_3 & 0 & \ddots & 0 \\ \cdots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \cdots \\ \cdots & \ddots & \ddots & \ddots & 0 & 1 & p_i & q_i & 0 \\ \cdots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \cdots \\ 0 & \ddots & \ddots & \ddots & \ddots & \ddots & 0 & 1 & p_{N-2} \\ 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 1 \end{bmatrix}.$$

After multiplication the matrices $\boldsymbol{UWU^T}$ and from the equation $\boldsymbol{B} = \boldsymbol{UWU^T}$ we have

$$\lambda_1 = w_1, \quad \vartheta_1 = p_1 w_1, \quad \eta_1 = q_1 w_1,$$
$$\lambda_2 = p_1^2 w_1 + w_2, \quad \vartheta_2 = p_1 q_1 w_1 + p_2 w_2, \quad \eta_2 = q_2 w_2$$
$$\lambda_3 = q_1^2 w_1 + p_2^2 w_2 + w_3, \quad \vartheta_3 = p_2 q_2 w_2 + p_3 w_3, \quad \eta_3 = q_3 w_3$$

....

$$\lambda_k = q_{k-2}^2 w_{k-2} + p_{k-1}^2 w_{k-1} + w_k, \quad \vartheta_k = p_{k-1} q_{k-1} w_{k-1} + p_k w_k, \quad \eta_k = q_k w_k$$

....

$$\lambda_{N-3} = q_{N-5}^2 w_{N-5} + p_{N-4}^2 w_{N-4} + w_{N-3}, \vartheta_{N-3} = p_{N-4} q_{N-4} w_{N-4} + p_{N-3} w_{N-3}, \ \eta_{N-3} = q_{N-3} w_{N-3}$$
$$\lambda_{N-2} = q_{N-4}^2 w_{N-4} + p_{N-3}^2 w_{N-3} + w_{N-2}, \ \vartheta_{N-2} = p_{N-3} q_{N-3} w_{N-3} + p_{N-2} w_{N-2}$$
$$\lambda_{N-1} = q_{N-3}^2 w_{N-3} + p_{N-2}^2 w_{N-2} + w_{N-1}.$$

From the above mentioned equalities there are determined the elements p_i, q_i, w_i of the matrices $\boldsymbol{U}$ and $\boldsymbol{W}$ and the recursive formulae

$$w_1 = \lambda_1, p_1 = \frac{\vartheta_1}{w_1}, q_1 = \frac{\eta_1}{w_1}$$
$$w_k = \lambda_k - w_{k-1} p_{k-1}^2 - w_{k-2} q_{k-2}^2,$$
$$p_k = \frac{1}{w_k}(\vartheta_k - w_{k-1} p_{k-1} q_{k-1}),$$
$$q_k = \frac{\eta_k}{w_k}, \quad k = 1, \dots, N-1,$$

where

$$q_{-1} = q_0 = p_{-1} = p_0 = w_{-1} = w_0 = \vartheta_{N-1} = \eta_{N-1} = \eta_{N-2} = 0.$$

To find the solution $\boldsymbol{M}$ of the system of equations $\boldsymbol{BM}=\boldsymbol{G}$ i.e. $\boldsymbol{UWU^TM}=\boldsymbol{G}$ we need to solve two systems of equations consecutively:

$$\boldsymbol{UZ}=\boldsymbol{G} \quad \text{and} \quad \boldsymbol{WU^TM}=\boldsymbol{Z}, \tag{21}$$

according to the formulae

$$z_k = g_k - z_{ki-1}p_{ki-1} - z_{k-2}q_{k-2}, \quad k=1,\dots,N-1$$
$$m_{N-1}=\frac{z_{N-1}}{w_{N-1}}$$
$$m_k=\frac{z_k}{w_k}-m_{k+2}q_k-m_{k+1}p_k, \quad k=N-2,\dots,1,$$

where

$$q_{-1}=q_0=z_{-1}=z_0=m_N=0.$$

After determining the vector $\boldsymbol{M}$ we should determine also the values of the smoothing spline function in the knots. Taking under consideration (16) we obtain

$$\hat{y}_k=\tilde{y}_k-\rho_k D_k, \tag{22}$$

where

$$D_0=\frac{m_1}{h_1},$$
$$D_1=((-\frac{1}{h_1}-\frac{1}{h_2})m_1+\frac{m_2}{h_2}),$$
$$D_k=(\frac{m_{k-1}}{h_k}+(-\frac{1}{h_k}-\frac{1}{h_{k+1}})m_k+\frac{m_{k+1}}{h_{k+1}}), \qquad k=2,\dots,N-2 \tag{23}$$
$$D_{N-1}=(\frac{m_{N-2}}{h_{N-1}}+(-\frac{1}{h_{N-1}}-\frac{1}{h_N})m_{N-1}),$$
$$D_N=\frac{m_{N-1}}{h_N}.$$

Moreover from (16) we get

$$\widehat{\boldsymbol{Y}}-\widetilde{\boldsymbol{Y}}=-\kappa\boldsymbol{RH^TM}. \tag{24}$$

Hence it is easy to compute the sum of squares of the deviations of the spline $\hat{y}(x_k)$ from the measurements $\tilde{y}_k$ in the points $x_k, \quad k=0,1,\dots,n$:

$$S^2=\sum_{k=1}^{n}[\hat{y}_k-\tilde{y}_k]^2=(\widehat{\boldsymbol{Y}}-\widetilde{\boldsymbol{Y}})^T(\widehat{\boldsymbol{Y}}-\widetilde{\boldsymbol{Y}})=(-\kappa\boldsymbol{RH^TM})^T(-\kappa\boldsymbol{RH^TM})= \qquad =$$
$$\kappa^2\boldsymbol{M}^T(\boldsymbol{H^T})^T\boldsymbol{R}^T\boldsymbol{RH}^T\boldsymbol{M}.$$

Knowing that $\mathbf{R}^T=\mathbf{R}$ we have

$$S^2=\kappa^2\boldsymbol{M}^T\boldsymbol{HR}^2\boldsymbol{H}^T\boldsymbol{M}. \tag{25}$$

Therefore the variation D^2r of the errors $r_k=\hat{y}_k-\tilde{y}_k, \quad k=0,1,\dots,N$ can be determined from the formula: [5], [6]

$$D^2r=\frac{S^2}{N+1}. \tag{26}$$

To estimate the approximation of the signal $y=y(x)$ we use the coefficient of concordance [3]

$${\phi_y}^2=\frac{\sum_{k=1}^{n}[\tilde{y}_k-\hat{y}_k]^2}{\sum_{k=1}^{n}[\tilde{y}_k-\bar{y}_k]^2}, \quad \bar{y}=\frac{\sum_{i=0}^{n}\tilde{y}_i}{n+1} \tag{27}$$

and the linear correlation coefficient

$$R=\sqrt{1-\phi_y^2}. \tag{28}$$

The coefficient ϕ_y^2 takes the values from [0,1] and defines the concordance of the determined curve $\hat{y}=\hat{y}(x)$ with the measured values $\tilde{y}_i$. That concordance is the better the lower is the value of φ_y^2. If the value of φ_y^2 converges to zero then the correlation coefficient converges to one. The correctness of the approximation can be evaluated on the basis of the residuals analysis

$$e_k \equiv e(x_k) := \tilde{y}(x_k) - \hat{y}(x_k), \quad k = 0,1,\ldots,N.$$

Determining the smoothing spline we have to keep in mind that it is very important to choose the weights $\rho_k, k = 0,1,\cdots,n.$ If $\rho_k = 0, k = 0,1,\cdots,n$ then from (19) it follows that

$$\hat{y}_k = \tilde{y}_k, \quad k = 0,1,\ldots,N.$$

Then the smoothing spline function $\hat{y}$ is the interpolating spline function passing through the measured points $\tilde{y}_k,\ k = 0,1,\ldots,N$ and it does not eliminate the measurements errors.

Decreasing the weights give access to decreasing the differences $r_k = |\hat{y}_k - \tilde{y}_k|,\ \ k = 0,1,\ldots,N$ and then the curve $\hat{y}$ passes closer the measured points while increasing the weights provides to the increasing the differences r_k. Assume that the values $\tilde{y}_k$ are burthened with the measurements errors δ_k, i.e. $|y_k - \tilde{y}_k| \leq \delta_k$, where y_k are the measured values. Assume also that the unknown values y_k of y are disturbed by the white noise $\{\varepsilon_k\}$ with the mean value $E(\varepsilon) = 0$, the correlation $E(\varepsilon_\nu \varepsilon_\mu) = 0$ for $\nu \neq \mu$ and $E\varepsilon^2 = 0$, the variance $E(\varepsilon^2) = \sigma^2$. Additionally we assume that the noise has the normal distribution. Therefore the smoothing spline function $\hat{y}$ should satisfy the inequalities

$$|\hat{y}_k - \tilde{y}_k| \leq \delta_k, \quad k = 0,1,\ldots,N. \tag{29}$$

Included (19) we obtain

$$|\hat{y}_k - \tilde{y}_k| \leq \rho_k |D_k| \ \leq \delta_k, \quad k = 0,1,\ldots,N.$$

Consulting (17) the unknown moments m_k and weights ρ_k are able to be determined recursively from:

$$(\boldsymbol{A} + 6\kappa \boldsymbol{H}\boldsymbol{R}^{(j)}\boldsymbol{H}^{\boldsymbol{T}})\boldsymbol{M}^{(j)} = 6\boldsymbol{H}\widetilde{\boldsymbol{Y}} \tag{30}$$

$$\rho_k^{(j+1)} = \begin{cases} \frac{\delta_k}{|D_k^{(j)}|} & \text{for} \quad D_k^{(j)} \neq 0 \\ 0 \quad \text{for} \quad D_k^{(j)} = 0 \end{cases}, \tag{31}$$

where j - the number of iteration. The iteration process of determining the weights $\rho_k^{(j)}$ is broken when the following inequalities take part

$$|\hat{y}_k^{(j)} - \tilde{y}_k| > \delta_k, \quad k = 0,1,\ldots,N.$$

In real realizations of the elaborated algorithm instead of (31) the following formula

$$\rho_k^{(j+1)} = \begin{cases} \Theta \frac{\delta_k}{|D_k^{(j)}|} & dla \quad |D_k^{(j)}| \geq \chi \\ 0 \quad dla \quad |D_k^{(j)}| < \chi \end{cases},$$

where $\Theta < 1$ can be accepted. The coefficient Θ should not take the value close to one. Quite good results are obtained when $\Theta = 0.9$. The constant χ is chosen dependently on δ_k and on measurements accuracy.

Using the formula (16) we construct the spline function $\hat{y}$ depending on its moments

$$\hat{y}(x) = m_{k-1}\frac{(x_k - x)^3}{6h_k} + m_k\frac{(x - x_{k-1})^3}{6h_k} + (y_{k-1}^0 - \frac{m_{k-1}h_k^2}{6})\frac{x_k - x}{h_k} + \\ \ldots + \left(y_k^0 - \frac{m_k h_k^2}{6}\right)\frac{x - x_{k-1}}{h_k} \ \text{ for } \ x_{k-1} \leq x \leq x_k, \quad k = 1,\ldots,N.$$

Substituting $x_k = x_{k-1} + h_k$ the function s can be presented as

$$\hat{y}(x) = a_k + b_k(x - x_{k-1}) + c_k(x - x_{k-1})^2 + d_k(x - x_{k-1})^3 \text{ dla } x \in [x_{k-1}, x_k],$$

where

$$a_k = \hat{y}_{k-1}, \qquad b_k = \frac{\hat{y}_k - \hat{y}_{k-1}}{h_i} - \frac{2m_k + m_{k+1}}{6}h_k,$$

$$c_k = \frac{m_{k-1}}{2}, \qquad d_k = \frac{m_k - m_{k-1}}{6h_k}, \quad k = 1,\ldots,N.$$

4. NUMERICAL EXAMPLE

To illustrate the elaborated method there were made, with the accuracy of reading 0.1 [...^{0}], the measurements of submerged angle the of the submarine caused by water movement in the trim reservoirs from the stern to the bow [3]. The ship was sailing at a speed of 4.19 [m/s].

Table 1 contains the measurement values $\tilde{\psi}_k$, the values determined from the model $\hat{\psi}_k$ and the values of the differences $r_k = \tilde{\psi}_k - \hat{\psi}_k$. Table 2 contains the determined coefficients of the function $\hat{\psi}$ and the determined weights ρ_k obtained after 7th iteration. The measurements of the trim angle $\tilde{\psi}(t)$ and the estimator $\hat{\psi}(t)$ are shown in Figure 1. Figure 2 presents the graph of residuals.

Table 1 Measurements values

k	t_k $[s]$	$\tilde{\psi}(t)$ $[\ldots^0]$	$\hat{\psi}(t)$ $[\ldots^0]$	$r_k = \tilde{\psi}(t_k) - \hat{\psi}(t_k)$ $[\ldots^0]$
0	0	0.	-0.0207615	-0.00766343
1	10	0.2	0.207663	-0.00766343
2	20	0.5	0.520732	-0.0207324
3	30	1.0	0.980968	0.0190317
4	40	1.5	1.50318	-0.00317548
5	50	2.2	2.19527	0.0047322
6	60	2.7	2.69688	0.00311807
7	70	3.5	3.50381	-0.00380956
8	80	5.0	4.99754	0.0024645
9	90	6.0	6.00189	-0.00189016
10	100	6.5	6.47761	0.0223931
11	110	6.5	6.45702	0.0429772
12	120	6.2	6.23117	-0.0311705
13	130	6.2	6.17565	0.0243533

Table 2 Determined coefficients of $\hat{\psi}$

a_k	b_k	c_k	d_k	ρ_k
-0.0207615	0.0210102	0	0.0000183229	338.095
0.207663	0.0243555	0.000549686	0.0000145451	57.4095
0.520732	0.0407275	0.00098604	-0.0000456435	27.5622
0.980968	0.0491094	-0.000383266	0.0000694396	3.01096
1.50318	0.062843	0.00169992	-0.000106333	3.54259
2.19527	0.0534322	-0.00149008	0.0001163	103.946
2.69688	0.0485735	0.00199892	0.0001213	1.3494
3.50381	0.127916	0.00563791	-0.00034922	0.941608
4.99754	0.140124	-0.00483884	0.0000869971	3.1596
6.00189	0.0711317	-0.00222893	-0.0000127076	66.2023
6.47761	0.0196764	-0.00261016	0.0000436677	268.742
6.45702	-0.0166161	-0.00130013	0.0000703211	53.3899
6.23117	-0.0109491	0.000809506	-0.0000269835	150.421

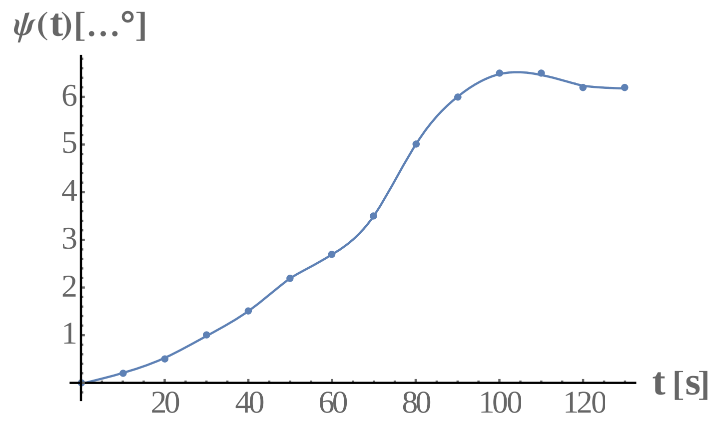

Figure 1 The measurements of the trim angle $\tilde{\psi}(t_k)$ and its approximated process $\hat{\psi}(t_k)$ showed in Table 1

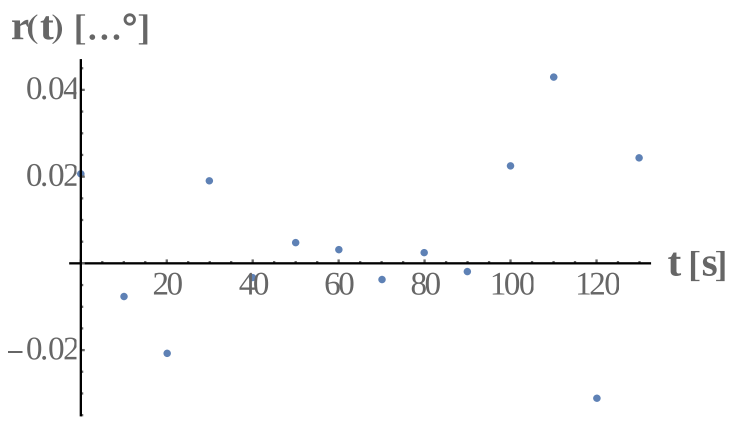

Figure 2 The graph of residuals $r(t_k) = \tilde{\psi}(t_k) - \hat{\psi}(t_k)$ presented in Table 1

To assess the approximation of the trim angle $\hat{\psi}(t_k)$ process there is used the coefficient of determination

$$R_\psi = \sqrt{1 - \Phi_\psi^2} \ ,$$

where

$$\Phi_\psi^2 = \frac{\sum_{i=0}^{n}(\tilde{\psi}_i - \hat{\psi}_i)^2}{\sum_{i=0}^{n}(\tilde{\psi}_i - \bar{\psi})^2}, \quad \bar{\psi} = \frac{1}{n+1}\sum_{i=0}^{n}\tilde{\psi}_i.$$

The coefficient R_ψ determines the compliance of the curve $\hat{\psi}(t)$ with empirical values. The compatibility is the better the value R_ψ is closer to unity. For the approximation of the trim angle the value of the coefficient is $R_\psi = 0{,}99992$ which means that the determined function describes the change of the trim angle very well.

5. CONCLUSIONS

Smoothing spline functions are usually used in numerical methods when given measurement points are burdened with errors. Knowing the coefficients of smoothing splines it is easy to provide formulas for integrals and derivatives The fact is important in modelling the equations of motion of floating objects. The advantage of the given signal approximation algorithm is that the measurement data need not be recorded at equidistant moments of time.

REFERENCES

[1] Mańczak K., Nahorski Z.: *Komputerowa identyfikacja obiektów dynamicznych,* PWN, Warszawa 1983.

[2] Marczuk G. I.: Analiza numeryczna zagadnień fizyki matematycznej, PWN, Warszawa 1983.

[3] Stępień Z.,*Badanie wpływu pływalności szczątkowej na parametry ruchu okrętu podwodnego*. Praca magisterska, WSMW Gdynia 1981

[4] Stieczkin S., Subbotin J.: *Splines in mathematics,* Science, Moscow 1976.

[5] Załęska-Fornal A., Zellma M., 2002: *Application of Basic Splines to the Identification of Sailing Object Equations,* ZN Nr 65, Wyższa Szkoła Morska w Szczecinie, EXPLO-SHIP, pp. 375-386.

[6] Załęska-Fornal A, Zellma M., 2012: *Zastosowanie wielomianowych funkcji sklejanych do identyfikacji równania opisującego zmiany kąta przegłębienia okrętu podwodnego*. Czasopismo Technika Transportu Szynowego, nr 9, ISSN 1232-3829.

[7] Zawiałow J., Kwasow B., *Splines methods,* Science, Moscow 1980.

[8] Zellma M., Załęska-Fornal A., 2004: *Krzywoliniowa funkcja regresji w bazie funkcji sklejanych*, Zeszyty Naukowe AMW, Rok XLV, Nr3 (158) ,pp. 119-134.

MULTI-CRITERIA ANALYSIS OF CROATIAN PORT SYSTEM FOR IMPLEMENTATION OF SUSTAINABLE MOTORWAYS OF THE SEA SERVICES

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Summary

Motorways of the Sea are maritime services, integrated in a logistic door-to-door chain, which use sustainable, regular, frequent, high quality and reliable short sea shipping connections. Motorways of the Sea are a practical example of the definition of combined (sustainable) transport. It is an intermodal transport method, where the maritime component represents the major portion of the route. The Motorways of the Sea system does not require significant infrastructural investments in ports; however, the success of the service implies an excellent integration with the other methods of transport, in the first place railway and road transport. With respect to the current model of functioning of the transport system in the Republic of Croatia, where the development of the port and of the gravitational transport system is left over to each individual port (six independent ports), and where there is no systematic specialisation for each port or route, the results of the analysis are devastating. They witness that the current Motorways of the Sea implementation model is completely inappropriate and there is not even one element that could justify its maintenance. The analysis indicates the conclusion, that is, that a scientific approach, which includes the identification of all relevant factors, the analysis of the entire transport infrastructure, as well as the identification of criteria which affect the functioning of the Motorways of the Sea system, can surely and correctly define which is the optimal model for the introduction of a sustainable Motorways of the Sea system, but also provide an evaluation of the existing model. From the impact analysis of each single criteria, as well as of all combinations, it may be concluded that with the implementation of a sustainable system, on the example of the transport system in the Republic of Croatia, two scenarios (models) can be singled out as optimal choices. These are the two ports and the regionally grouped port models. The choice on which model to choose, will depend on the initiative we are dealing with (state or private transport operators), and whether there is a common development approach.

Keywords: Motorways of the Sea, port system, multi-criteria analysis, Republic of Croatia, scenarios

1. INTRODUCTION

The subject of this article is to research, elaborate and consistently define all the relevant aspects and factors, necessary for the successful implementation of a sustainable Motorways of the Sea system. Moreover, in accordance with this, to suggest a model, measures and activities aimed to create a sustainable Motorways of the Sea system, which would then enable a further growth and development of intermodal transport, but also of the economic system.

Traffic, in particular road transport, as one mode of transport, causes a negative impact both on the environment and society. This negative impact is especially noticeable through frequent traffic congestions through a higher risk of traffic accidents, a higher level of noise, and exhaust gases, directly emitted by transport vehicles into the environment. Along with the above mentioned, there are also secondary negative impacts, such as the quantity of gases emitted in the production process of motor fuels, an increased level of stress from all traffic participants and many others. All this clearly demonstrates that road transport has certain limits, with an expressed, negative influence on the environment and society. At the same time, the absence of a free area for expansion and the lack of civil protests against the construction of new roads, result in an increase of the costs of road construction and maintenance. The conclusion is that all the above mentioned, first and for most the financial limits, have contributed to the cognition that it is more than necessary to find and develop alternative traffic solutions, such as short sea shipping and Motorways of the Sea that includes two or more transport modes. In this sense, a port represents the hub where transport technologies (road, railroad, ship, barge) conjoin. In order to ensure the competitiveness of the intermodal system, with respect to conventional road transport, a port has to be very flow-through. The major threats here, regard capacity, the efficiency of transhipment and interactions with the other transport modes. In the process of transport planning, the choice of a port affects significantly the route for the further transport to the final destination. A route that is more competitive and attracts a larger quantity of freight, will also achieve a greater social and economic effect in that area. For this reason, this research is focused on the port system and related traffic infrastructure.

In this paper we will use the multi-criteria analysis method, in order to be able to make a clear difference when comparing various scenarios of implementation of sustainable Motorways of the Sea services at a regional and national level.

1.1. Past research

By analysing relevant scientific and professional literature works from the field of subject, that is research papers that could help solving the presented issue, it is possible to separate the following studies and authors: Baird, A.: *EU Motorways of the Sea Policy* from 2005, where the author presents measures taken by the European Commission in the attempt to develop Motorways of the Sea systems, as well as the activities that are being undertaken. In thee study *The Economics of Motorways of the Sea from 2008,* the same author presents the system's relevant elements and the economic aspect and advantages in comparison with land transport. D. Tsamboulas, P. Moraiti, E. Vlahogianni in the study *Assessing the Effect of Infrastructure and Service Attributes on the Motorways of the Sea Realization* present Bayesian networks as a relevant model to evaluate different scenarios in function of transport development. Tsamboulas D., Lekka, A. M., Moraiti, P. in the study *Evaluation of Motorways of the Sea for Developing Countries,* from 2011, present a model where they analyse potential corridors and develop port clusters, among which it is possible to develop a Motorways of the Sea service.

Based on the research carried out and based on the analysis of the relevant literature, the conclusion is that within the available literature, no one, up to this point, has systematically elaborated the issue of an analysis of the potential of a determined traffic route, with the included ports, with the aim to initiate sustainable Motorways of the Sea services.

2. RELEVANT CRITERIA FOR A SUCCESSFUL IMPLMENTATION OF THE MOTORWAYS OF THE SEA SYSTEM

The direction in which ports, in a certain area, will develop, specialise and associate, or not, is difficult to define without a systemic analysis of the criteria set to achieve a successful Motorways of the Sea system.

The criteria for successfulness, according to which it is possible to evaluate the suggested models for the implementation of a Motorways of the Sea system, are the following: infrastructural, interaction with different transport modes and administrative-political.

2.1. Infrastructural criteria

The infrastructural criteria analysis, clearly indicates that infrastructure is key to ensure the reliability of the system and that only an infrastructure with sufficient capacities can provide for the concentration of a large freight flow through the route. It can be noticed that the major difference among ports within the Republic of Croatia, lies in the port availability and infrastructure on the land - based side of the terminal.

The construction of the appropriate infrastructure, whether it is about road or railroad connections, or a terminal, requires significant financial means and it usually does not depend on the mere terminal, but on a national political decision. Here it is possible to clearly see the mutual connection with the other criteria.

2.2. Criteria of interaction with different transport modes

The fact that an interaction between different transport modes takes place in a port, makes that single port an important link in the creation of competitiveness for the Motorways of the Sea system. Equally important are also the communication and flow-through of that interaction with ships, railroad or road systems, as if only one connection is not impeccable, it will impact the reliability and quality of the entire system and service. This is a criteria where a major role is covered also by external factors, such as railroad and maritime operators. However, the function and responsibility of a port is to find a common way and a common solution to conform completely and raise the quality level. Interaction does not regard only the execution of services and connections, but also communication. The organisation of road transport is very simple. There is no interaction with other transport modes, nor exchange of documents among a large number of participants. In the case of Motorways of the Sea systems that is precisely the case and a major threat is represented by the lack of a flow-through and reliable service. Information technology can compensate this threat and its implementation in the system and use by all users is necessary. Unfortunately, ports have not entirely recognised this need and they surely lose a valuable element in relation to the competitiveness of routes.

2.3. Administrative-political criteria

Administrative-political criteria may be divided in two sub-criteria groups:

1) Criteria that regard the service management system (*service promotion sub-criteria, service information support sub-criteria, systemic identification of service's narrow throat sub-criteria and systemic service's quality management sub-criteria*) and
2) Criteria that regard the port system management.

Both groups of sub-criteria are very important for the analysis of the possible models of introduction of Motorways of the Sea systems. The first group of sub-criteria is made by a group of activities whose aim is to additionally raise the level of competitiveness of the system towards road transport modes and competitive routes. The activities are not implemented in the Republic of Croatia, but their development and introduction must definitely be encouraged.

The second criteria regard the possibility to associate more ports (nationally or regionally) in a port cluster, which would increase the capacity of the ports, but it also additionally complicates the management of such a larger and more complicated port system.

The model analysis, carried out based on the criteria and sub-criteria, will allow national bodies to decide on whether to encourage the development of all ports equally, or to concentrate investments in one or two routes.

The chosen criteria are the result of conclusions, based on research and surveys aimed at defining models, measures and activities for the implementation of a sustainable Motorways of the Sea system.

The Republic of Croatia, its maritime ports and traffic system, including regional ports, have been chosen to test the suggested models. Therefore, the identified models have been modified according to the terms and to the current condition of the transport system in the Republic of Croatia. In this way concrete scenarios, which will be analysed by using the previously defined criteria, will be defined.

Based on the set criteria, the port system in the Republic of Croatia is ideal for modelling and analysis for many reasons. The following are some of its particularities:

- The port system is composed by six equal ports, without preferences in the current functioning and development,
- All ports are developed relatively weakly from an infrastructural and organisational point of view, hence a significant progress in terms of successfulness and effectiveness, is possible
- Port systems in the surroundings have a lot of very developed ports in various countries (Italy, Slovenia, Montenegro, Albania, Greece),
- Successful Motorways of the Sea services pass through some of the ports in the surroundings and they represent a positive example of successfulness in the European Union,
- The largest part of the traffic through Croatian ports is destined in the countries of the European Union,
- Part of the traffic through Croatian ports is destined outside of the countries of the European Union.

2.4. Scenarios

Therefore, the multi-criteria decision-making process has been conducted for the following scenarios:

- Scenario based on the model of independent ports: Rijeka, Zadar, Šibenik, Split, Ploče and Dubrovnik.
- Scenario based on the model of nationally grouped ports:
- The port of Rijeka, which represents a unit per se,
- Ports of the Central Dalmatian area: Zadar, Šibenik and Split,
- Ports of the Southern Dalmatian area: Ploče and Dubrovnik.
- Scenario based on the model of regionally grouped ports:
  - North Adriatic ports: Venice, Trieste, Koper and Rijeka
  - Ports of the Central Dalmatian area: Zadar, Šibenik and Split, and
  - Ports of the Southern Dalmatian area: Ploče and Dubrovnik.
- Scenario based on the model of a single port – Rijeka: Rijeka as port of national priority for Motorways of the Sea services.
- Scenario based on the model of two ports – Rijeka and Ploče: the ports of Rijeka and Ploče equally developed and holding the same status with regard to the container and RO-RO traffic.
- Scenario based on the model of "simple ports": the port of Zadar, theoretically set as a port that functions based on the model of "simple ports", in the area of the new container and RO-RO port in Gaženica. The reason why the port of Zadar has been chosen, in comparison to other ports in the Republic of Croatia, is because of its relatively developed and available traffic infrastructure in the area of Gaženica, its relatively large terminal space, because of the ongoing works on the construction of a RO-RO terminal, as well as the prepared planning-technical documentation for the container terminal. The fact that the construction of the container terminal has not yet started goes in fa-

vour, as an eventual use and functioning of the terminal according to the model of "simple ports", would require a modification of the planning-technical documentation and the construction of the terminal according to somewhat different principles.

3. MULTI-CRITERIA ANALYSIS IN FUNCTION OF THE IMPLEMENTATION AND DEVELOPMENT OF MARITIME ROUTES

The use of a multi-criteria analysis process is common when elaborating and analysing different traffic issues and strategies. Considering the research subject, the use of a multi-criteria analysis process is favourable and applicable, as it allows a further analysis through the modification of the entry parameters of the research. Also, very significant, is the fact that when using a multi-criteria analysis process, there are many high-quality computer programmes, which speed up and improve the mere analysis.

In comparison to different combinations of criteria weight, the multi-criteria analysis process allows analysis and optimisation.

3.1. Definition of criteria weight

In this paper, only one combination of criteria weight has been considered. The latter has been determined in accordance with:

- previously made analysis of the traffic system and of the system of maritime ways, as well as with the identification of criteria, sub-criteria and their influence and significance on the implementation of Motorways of the Sea services,
- a questionnaire, in which the candidates have evaluated the offered criteria.

In order to carry out the multi-criteria analysis process, the computer programme PROMETHEE (version 1.3.1.0. – A*cademic Edition*) has been used during the research.

According to the specifications of the programme used, when comparing scenarios through a multi-criteria decision-making process, it is necessary to define the weight of each single criteria in relation to the other criteria. In this way, through a change of weight (significance) of the single criteria and sub-criteria, we enable a scenario analysis from various angles, that is, an active observation, analysis and search for the optimal scenario, depending on the wishes and possibilities of the decision-maker.

When analysing and searching for an optimal solution for the implementation of a sustainable Motorways of the Sea system, it is not possible to use past researches and defined criteria weights, as they do not exist in world literature. Hence, it is necessary to define the levels of weight and the relations between criteria and sub-criteria. Considering that the implementation of sustainable Motorways of the Sea depends on three levels of criteria weights (transport operators, port operators and the State), it makes sense to proceed in relation to the inclusion of each of them.

In this way, it is possible to assign weights depending on the development approach, and therefore they can be divided in:

- Significant financial investment
- Significant efforts by transport operators, or
- State initiative, along with the coordination of participants, with minimal financial burden.

In this case, the infrastructural criteria regards infrastructural investments encouraged and financed by the State and the port operator; the criteria of interaction with different transport modes regards the development of services through a transport (road, railroad and seaway) initiative, while the administrative-political criteria is the least financially demanding and looks for a State initiative, along with the support of all participants included. Depending The criteria and sub-criteria weights and, consequently, the result of the multi-criteria decision-making, will depend precisely on the approach chosen.

Taking into consideration the research conclusions reached so far, the identified scenario will be analysed through a couple of different levels and combinations of criteria and sub-criteria weights. The scale was made including:

- only infrastructural criteria,
- only criteria of interaction with different transport modes,
- only administrative-political criteria,
- simultaneous influence of infrastructural criteria and criteria of interaction with different transport modes,
- simultaneous influence of infrastructural and administrative-political criteria,
- simultaneous influence of administrative-political criteria and criteria of interaction with different transport modes, and
- simultaneous influence of administrative-political, infrastructural and criteria of interaction with different transport modes.

Criteria weights, through which the significance considered upon the process of multi-criteria evaluation of scenarios will be assessed, are shown in table 1.

Table 1 Criteria weight

Significance of the criteria in combination	Criteria weight
Criteria not taken into consideration	0
Minor criteria weight	1
Average criteria weight	2
Large criteria weight	3

Source: Made by the author

The criteria that will not be taken into consideration during the evaluation, through the process of multi-criteria analysis, will be assigned the value 0, while the others will be given a value from 1 to 3, depending on their weight. The reason for this, is to be found in the large number of sub-criteria; it is therefore understandable, that not all sub-criteria are equally important.

The assignment of weight criteria to the infrastructural criteria, was made based on the following cognitions:

- Considering that extremely large financial investments are a common characteristic to all sub-criteria, the sub-criteria which require a new and significant infrastructural investment, have been evaluated with a large weight. These are the insurance (usually construction), of the direct connection to the railroad infrastructure, to the highway network, a sufficient railroad and road infrastructure capacity, a sufficient parking space capacity, the existance of a Terminal Operating System, an appropriate port equipment for the management of containers and vehicles, as well as an appropriate sea depth. All these are sub-criteria that must absolutely be fulfilled and represent the basic precondition to ensure the reliability of successful Motorways of the Sea systems. In case one of these sub-criteria is not met, it would be difficult to expect a long-term success of the Motorways of the Sea system through that specific route.
- Sub-criteria such as the factor of safety in the railroad or road infrastructure, the maintenance of railroad and road infrastructure and the condition and capacity of road infrastructure for internal and external vehicles in the terminal, have been evaluated with an average weight. This is due to the fact

that these are elements that can be compensated, as their defects can be reduced, if we are dealing with an extreme effort from the operator. Hence, with the railroad or road infrastructure process optimisation, but also thanks to the operator's experience, these sub-criteria can be brought to a level where they do not represent the narrow throat and where a major infrastructural investment is not needed.

- Sub-criteria that regard prioritisation upon admission of ships for regular service and exception from the use of tugboats or pilots, are not unfortunately in force or they do not exist, in the Adriatic systems, therefore they cannot be highly evaluated. These are organisational elements, for which it is assumed that their value will be recognised only in the future.

The assignment of weight criteria, including only criteria of interaction with different transport modes, was made based on the following cognitions and guidelines:

- Experience is an extremely important element when introducing new services, or ensuring the perfect functioning of the existing ones. Because of that, the current number of SSS services and block-trains is important and it has been given the highest value. Port terminals with no experience, or limited experience in serving regular maritime and railroad services, need a certain time to bring all processes to perfection, that is, to a complete the flow-through, which represents the precondition for Motorways of the Sea services. This regards all participants, not only terminal operators.
- The existance of a port communication service and the interaction with the road transport is very important in case of a major terminal burden, when terminals function on the upper limit of thir capacities. Considering that this is not the case with the observed ports, these sub-criteria have been evaluated with an average weight (weight 2).
- World examples show that the prioritisation status of the Motorways of the Sea services is of major importance when ensuring a complete freight flow-through; however, not even one of the analysed ports implements this option. Therefore, for an objective comparison, this sub-criteria has been evaluated with a minor weight. In case any of the ports should introduce the prioritisation of Motorways of the Sea services, this sub-criteria should be evaluated with a large weight.

The assignment of weight criteria to administrative-political criteria, including only administrative-political criteria, was made based on the following cognitions and guidelines:

- The system of service promotion, the system's informatic support, the systemic identification of narrow throats and the system of service quality management are all sub-criteria directly connected to the success of the service. They do not demand larger financial investments, but initiative and efforts by the responsible for the functioning of the port and of the traffic system. In the observed example, these are States and belonging Port Authorities, whose main interest should be traffic development in their area. These sub-criteria have been given a large weight, same as the political decision-making sub-criteria, which carries the strategic orientation of a State, in planning the traffic system. The consequence of this is the development of one or more routes, together with favorisation, at all levels, and capital investments in infrastructure.
- Considering that *experience in the functioning of port systems* can be a compensator for minor deviations from the ideal management of the group of ports, and considering the fact that all ports are located in the Member States of the European Union, this sub-criteria has been evaluated with an average weight.
- Globally seen, the *advantage of an increased capacity* is truly an advantage; however, from the aspect of service organisation and the fact that Motorways of the Sea systems have precisely defined ports of origin and destination, the fact that there are free capacities in another, and dislocated, port within the same group, does not represent a special advantage. Hence, this sub-criteria has been evaluated with a minor weight. The exception would be for cases where ports are very close and connected, which would allow the use of the free capacity of one port, as a storage space for the first port.

The assignment of weights based on the simultaneous influence of infrastructural and criteria of interaction with different transport modes, was made according to the following cognitions and guidelines:

- Considering that it is a coordinated initiative and State investment (Port Authority), as well as transport operators, it is necessary to set a prioritisation level for Motorways of the Sea services. Due to this, the *prioritisation for ship admission at regular service* and the *exception to use a pilot* sub-criteria, have been given a large weight.
- For the same reason, it is necessary to organise the terminal's activities in a way that ensures the maximum flow of the freight. The existence of a port communication service is compulsory, as the organisation of all these authorities, in function of the prioritisation of the Motorways of the Sea services. Both criteria have been marked with major weight.
- The other sub-criteria have been assigned criteria weight as described previously.

The explanations for the definition of criteria weights, to scale a scenario based on the simultaneous influence of infrastructural and administrative-political criteria, are equal to the previous explanations for each single criteria. This is the case with State investment in traffic infrastructure and related political decisions. Efforts made in the administrative-political criteria can also be organised by the State and Port Authority.

The assignment of weights to scale a scenario based on the simultaneous influence of administrative-political and criteria of interaction with different transport modes, was made according to the following cognitions and guidelines:

- Considering that we are dealing with a coordinated initiative, with efforts and investments of the competent State institution (administrative-political criteria) and with transport operators, who are usually of private ownership, in this case, the *political decision-making* sub-criteria loses its significance and, consequently, it will not be taken into consideration (assigned weight 0).
- On the other side, the sub-criteria of *interaction with road transport* and the existence of a port communication service, is directly connected and dependant to the sub-criteria of *informatic service support* and *service quality management system;* hence, a major weight will be assigned to them.
- The other sub-criteria have been assigned the weight given for the influence of single criteria, as in the previous explanations.

Finally, the combination of criteria weight for multi-criteria analysis decision-making, including the simultaneous influence of administrative-political, infrastructural and criteria of interaction with different transport modes have been made. The explanations for the defined criteria weights are equal to the previously mentioned explanations for a single criteria.

3.2. Application and results of the multi-criteria analysis

After having inserted the entry data, the computer programme PROMETHEE (version 1.3.1.0. – A*cademic Edition*) has made a scenario ranking, based on the given influences of the mere criteria, or their combination. The scenario ranking for the implementation of a sustainable Motorways of the Sea, on the example of the Republic of Croatia, is shown in table 2.

Table 2 Scenario ranking, according to the influence of determined criteria or combination of criteria

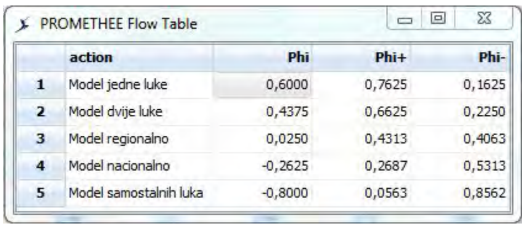
		Model of independent ports	Model of nationally grouped ports	Model of regionally grouped ports	Model of a single port	Model of two ports	Model of „simple ports“
CRITERIA INFLUENCE	Based on the infrastructural criteria	6	5	4	2	3	1
	Based on the criteria of interaction with different transport modes	4	2	1	6	3	5
	Based on the administrative-political criteria	6	4	5	3	2	1
	Based on the simultaneous influence of infrastructural and criteria of interaction with different transport modes	6	5	3	4	2	1
	Based on the simultaneous influence of infrastructural and administrative-political criteria	6	5	4	2	3	1
	Based on the simultaneous influence of administrative-political criteria and criteria of interaction with different transport modes	6	3	1	5	4	2
	Based on the simultaneous influence of administrative-political, infrastructural and criteria of interaction with different transport modes	6	5	4	3	2	1

Source: Made by the author

By analysing all the suggested scenarios, on the example of the traffic system in the Republic of Croatia, we can conclude that the "simple ports" scenario represents the optimal choice for the development and functioning sustainability of the Motorways of the Sea system. Such a port model of port is currently under development and we do not have an example of any port in the world that functions according to this model. The model has been analysed to hypothetically predict its effects and, at the same time, compare the advantages and disadvatages of such a system of ports, with regard to popular functionment methods.

Considering the superior results, in comparison with the other analysed models, the "simple ports" model should definitely be developed further on and its implementation encouraged. In our further analysis, this model will be omitted and the relation between the other models (scenarios) for a sustainable implementation of the Motorways of the Sea system, will be elaborated and described.

The computer programme allows a comparison between scenario preferences for the influence of each criteria and criteria combination. Figure 1 shows a scenario ranking, for the implementation of a sustainable Motorways of the Sea system, which includes only the infrastructural criteria.



PROMETHEE Flow Table

	action	Phi	Phi+	Phi-
1	Model jedne luke	0,6000	0,7625	0,1625
2	Model dvije luke	0,4375	0,6625	0,2250
3	Model regionalno	0,0250	0,4313	0,4063
4	Model nacionalno	-0,2625	0,2687	0,5313
5	Model samostalnih luka	-0,8000	0,0563	0,8562

Figure 1 Scenario ranking for the implementation of a sustainable Motorways of the Sea system, which includes only the influence of the infrastructural criteria, Source: computer programme Visual PROMETHEE

Source: Made by the author

According to figure 1, it is noticeable that when implementing a sustainable Motorways of the Sea, which includes only the infrastructural criteria, the weaker model in the rank is the model of independent ports. This is understandable, considering the fact that most infrastructural sub-criteria imply significant infrastructural investments in ports ad accesses to ports, hence investing in more ports definitely means a significant and unfavourable burden. In the same way, even the model of nationally grouped ports holds an unfavourable 4th position, while the model of regionally grouped ports is somewhat more advantageous and it is placed in the 3rdposition. Figure 1 clearly shows that the model of a single port holds the best position and has an optimal implementation, while the model of two ports is placed in the 2nd position. The computer programme assigns to each model (scenario) an indifference threshold (Phi).

While ranking the scenarios of implementation of a sustainable Motorways of the Sea, including only the influence of the criteria of interaction with different transport modes, the computer programme presents interesting results. In comparison to the previous scenario scale, in this specific ranking the results are completely opposite, which is shown in picture 2. The scenario of regionally grouped ports is the best choice, while the model of nationally grouped ports is positioned in the second place, followed by the model of two ports and the model of independent ports. Interestingly, the model of a single port can be found in the last position. When summing up this ranking, it has to be said that the influence of the criteria of interaction with different transport modes, is actually an initiative and an activity organised by the transport operators, and it does not include the influence of the State or a National Institution responsible for development (for instance, a Port Authority). Therefore, it is understandable and logical that operators can require and prefer a system that includes more ports and allows a larger choice, as well as the creation of a competitive relation, in order to be able to affect the price of services.

PROMETHEE Flow Table

	action	Phi	Phi+	Phi-
1	Model regionalno	0,7500	0,8472	0,0972
2	Model nacionalno	0,0417	0,2639	0,2222
3	Model dvije luke	-0,1111	0,2083	0,3194
4	Model samostalnih luka	-0,1806	0,1528	0,3333
5	Model jedne luke	-0,5000	0,0556	0,5556

Figure 2 Scenario ranking for the implementation of a sustainable Motorways of the Sea, which includes only the influence of the criteria of interaction with different transport modes; Source: computer programme Visual PROMETHEE

Source: Made by the author

A scenario ranking under the influence of an administrative-political criteria (figure 3), shows the model of two ports as the optimal solution, while the model of a single port is the next most favourable. The computer programme shows the model of regionally grouped ports as the next best option and the model of nationally grouped ports placed in the 4th position; however, with a very little preference threshold. This makes it almost equal to the model of regionally grouped ports. In the last position, we can see the model of independent ports.

PROMETHEE Flow Table

	action	Phi	Phi+	Phi-
1	Model dvije luke	0,3333	0,5833	0,2500
2	Model jedne luke	0,1806	0,5139	0,3333
3	Model regionalno	0,0556	0,5278	0,4722
4	Model nacionalno	0,0417	0,4583	0,4167
5	Model samostalnih luka	-0,6111	0,0972	0,7083

Figure 3 Scenario ranking for the implementation of a sustainable Motorways of the Sea system, which includes only the influence of the administrative-political criteria; Source: computer programme Visual PROMETHEE

Source: Made by the author

What follows, is a scenario ranking for the simultaneous influence of two or more criteria, which allows a view on situations when the development is planned and conducted in combination with national investments and initiatives, as well as with commercial investments by transport operators.

Figure 4 shows a scenario ranking for the implementation of a sustainable Motorways of the Sea system with the simultaneous influence of the infrastructural criteria and the criteria of interaction with different transport modes. The computer programme Visual PROMETHEE sets the model of two ports as the optimal solution, while the model of regionally grouped ports can be found in the second position and the model of a single port in the third position. Next, is the model of nationally grouped ports, while the model of independent ports is represented as the worse solution.

PROMETHEE Flow Table

	action	Phi	Phi+	Phi-
1	Model dvije luke	0,2540	0,4762	0,2222
2	Model regionalno	0,2063	0,4921	0,2857
3	Model jedne luke	0,2063	0,4762	0,2698
4	Model nacionalno	-0,1310	0,2460	0,3770
5	Model samostalnih luka	-0,5357	0,0833	0,6190

Figure 4 Scenario ranking for the implementation of a sustainable Motorways of the Sea system, which includes the influence of the infrastructural criteria and the criteria of interaction with different transport modes; Source: computer programme Visual PROMETHEE

Source: Made by the author

When ranking a scenario of simultaneous influence of the infrastructural and administrative-political criteria (figure 5), the model of a single port dominates and thus it represents the optimal solution, followed by the model of two ports, the model of regionally grouped ports and the model of nationally grouped ports, as second, third and fourth ranked models. The worse solution is represented by the model of independent ports, which can be found in the last position.

PROMETHEE Flow Table

	action	Phi	Phi+	Phi-
1	Model jedne luke	0,4781	0,6886	0,2105
2	Model dvije luke	0,4211	0,6447	0,2237
3	Model regionalno	0,0000	0,4386	0,4386
4	Model nacionalno	-0,1623	0,3246	0,4868
5	Model samostalnih luka	-0,7368	0,0702	0,8070

Figure 5: Scenario ranking for the implementation of a sustainable Motorways of the Sea system, which includes the influence of the infrastructural and administrative-political criteria; Source: computer programme Visual PROMETHEE.

Source: Made by the author

In the following ranking, we can make a comparison and conclude that, when ranking a scenario where we take into consideration the influence of the criteria of interaction with different transport modes, the best ranked scenario is the model of regionally grouped ports. This is shown when ranking more combinations, but it is also understandable given the fact that different transport operators can find their interest in a system where there is a multitude of ports, more combinations and transport routes. What is more, in such a competitive relation, better commercial conditions can also be requested. The following two best ranked scenarios are the model of nationally grouped ports and the model of two ports but, in their case, the preference threshold is very low (0,0662), which means that the difference is almost insignificant. The worse solution is represented by the model of a single port, while the model of independent ports is somehow better ranked and it can be found in the 4th position, as shown in figure 6.

PROMETHEE Flow Table

	action	Phi	Phi+	Phi-
1	Model regionalno	0,5147	0,7426	0,2279
2	Model nacionalno	0,0662	0,3529	0,2868
3	Model dvije luke	0,0662	0,3529	0,2868
4	Model samostalnih luka	-0,3235	0,1397	0,4632
5	Model jedne luke	-0,3235	0,1838	0,5074

Figure 6 Scenario ranking for the implementation of a sustainable Motorways of the Sea system, which includes the influence of the criteria of interaction with different transport modes and the administrative-political criteria; Source: computer programme Visual PROMETHEE

Source: Made by the author

The computer programme Visual PROMETHEE ranks scenarios which include the simultaneous influence of all three criteria (figure 7), by setting the model of two ports as the optimal solution, while the model of a single port and the model of regionally grouped ports are ranked as second and third solution. In the fourth place, we can find the model of nationally grouped ports, followed by the model of independent ports, placed in the weakest position.

PROMETHEE Flow Table

	action	Phi	Phi+	Phi-
1	Model dvije luke	0,2905	0,5372	0,2466
2	Model jedne luke	0,2331	0,5304	0,2973
3	Model regionalno	0,1824	0,5338	0,3514
4	Model nacionalno	-0,1149	0,3074	0,4223
5	Model samostalnih luka	-0,5912	0,0912	0,6824

Figure 7 Scenario ranking for the implementation of a sustainable motorways of the sea system, which includes the influence of the criteria of interaction with different transport modes, as well as the infrastructural and administrative-political criteria; Source: computer programme Visual PROMETHEE

Source: Made by the author

3.3. Strategic guideline suggestion for a possible model implementation in the Republic of Croatia

The analysis of the scenario ranking results demonstrates that the decision – that is, which method of implementation for a sustainable motorway of the sea system in the traffic system of the Republic of Croatia – is not a simple and unidirectional decision, but it depends on various elements. In the first place, these are the identified criteria, but also their weights, depending on the influence of the criteria. From the analysis of influence of each single criteria, as well as of all combinations, it may be concluded that, when implementing a sustainable Motorways of the Sea system in the example of the traffic system in the Republic of Croatia, two scenarios (models) can be separated as the optimal choice. These are the model of two ports and the model of regionally grouped ports. Which model to choose, will depend on whose initiative we are dealing with (State or private transport operators) and whether there is a common approach for development.

The model of two ports is an optimal solution for the implementation of a sustainable motorway of the sea system, in cases where the emphasis is placed on the administrative-political criteria, as well as on the simultaneous influence of the administrative-political criteria with the criteria of interaction with different transport modes. In the case of a simultaneous influence of the infrastructural and administrative-political criteria, the model of a single port is in great advantage, for the simple reason that the condition of the conjoin traffic infrastructure, as well as of the manipulation means in the terminal of the port of Ploče, is at a very low level. When the road infrastructure, which is currently under construction, will allow an indisturbed connection to the highway network and when the railroad infrastructure will be brought to a level of regular functioning, the model of a single port will not be dominant anymore, leaving space to the model of two ports, which will be in advantage. From all the above mentioned, it can be concluded that the model of two ports (figure 8) is the ideal solution for the implementation of a sustainable Motorways of the Sea system in all cases, except from the case where the influence of the criteria of interaction with different transport modes is dominant, together with the simultaneous influence of the administrative-political criteria and the criteria of interaction with different transport modes. In this case, the optimal choice is the model of regionally grouped ports (figure 9).

Figure 8 Model of implementation of a sustainable Motorways of the Sea, through two ports in the Republic of Croatia

Source: Made by the author

Figure 9 Model of implementation of a sustainable Motorways of the Sea system through regionally grouped ports

Source: Made by the author

It should be mentioned that the infrastructural and political-administrative criteria, require financial investments and burdens sustained by the State, hence in this sense, they are closely connected. The criteria of interaction with different transport modes, regards the activities and functionality of transport operators. In case the State should assess that its priority and interest lies in the orientation towards Motorways of the Sea services and that the implementation will be initiated and conducted by the State itself, independently, then these will be the criteria that will define the decision and the optimal model will be the model of two ports.

Equally valuable is also the decision-making on whether the State will initiate independently the implementation and persevere on the independent development of the Motorways of the Sea system or, on the contrary, if it will share the efforts of introducing the system with private transport operators. In the case of a common, coordinated and systemic introduction of a sustainable Motorways of the Sea system, the most ideal solution would be to develop a model of regionally grouped ports.

With respect to the current model of functioning of the traffic system in the Republic of Croatia, where the development of a port and gravitational traffic system is left over to each port independently (six independent ports – scenario 1), and where there is no systemic specialisation of each port, or route, the results of the analysis are devastating. They witness that the current model of implementation of the Motorways of the Sea system (considering also that the Motorways of the Sea systems are currently dominant in the entire European maritime exchange of goods), is completely wrong and that there is not even one element that could justify its maintenance. Therefore, the analysis suggests the conclusion that through a scientific approach, that includes the identification of all relevant factors, the current analysis of the condition of the entire traffic infrastructure and the identification of criteria that affect the functioning of the Motorways of the Sea system, can surely and precisely define which is the optimal model for the introduction of a sustainable Motorways of the Sea system, but also for the evaluation of the existing model.

Finally, the analysis of the research results, indicates four key conclusions for the case of the Republic of Croatia:

- The current functioning model of the traffic and port system in the Republic of Croatia is completely inappropriate for the development and implementation of a sustainable Motorways of the Sea system and it represents the worse solution with respect to all the identified models.
- The optimal solution is the development of one port and gravitational traffic infrastructure, based on the model of "simple ports". Considering that such a concept does not exist in the Republic of Croatia and that it is based on the complete specialisation of the port and of the traffic system for the simple and quick manipulation of the freight, without the presence of operators in terminals (with the independent activity of ship, road and railroad crew), we suggest the development and construction of a new port, that will be designed in this way and through which Motorways of the Sea services will be developed.
- In case the Republic of Croatia decides to neglect the development of Motorways of the Sea and this development is left over (independently) to transport operators, the ideal model is the model of regionally grouped ports. Such a model implies the coordination and common work of the port systems in more countries and objectively, except from the case where we are dealing with the same owners, the functioning of common port systems is quite difficult to achieve.
- In case the Republic of Croatia decides to actively participate in the development of a sustainable Motorways of the Sea system, independently or in coordination with transport operators, the optimal model is the model of two ports. This model means specialisation and preference of these two ports, a focus on infrastructural investments in these ports, while other ports are consciously left to the development of other types of freight and private investment. Except in case the model of "simple ports" is introduced, this model represents the optimal solution for the implementation of a sustainable Motorways of the Sea system in the Republic of Croatia.

These conclusions were generated from the analysis of the current infrastructure condition, of all the included and relevant factors, transformed in criteria and sub-criteria, and from the assignment of weights in relation to the combinations of their influence. The results of the analysis may surely be different, with the modification of any of these elements. In such a combination, models have been analysed for the case of the Republic of Croatia and according to the current infrastructure condition in Croatia. The analysis is definitely applicable in any traffic system in the world, whether it is a national system or a regional system. It may be expected that the same analysis, on the example of another national system, would result in different conclusions, but also that the indicated analysis results, on the example of the Republic of Croatia, can be affected by an intervention on the criteria, sub-criteria, on their weights or by a modification of the infrastructure condition.

4. CONCLUSIONS

Intermodal transport implies a transport that includes two or more transport modes. In this sense, a port represents the hub where transport technologies (road, railroad, ship, barge) conjoin. In order to ensure the competitiveness of the intermodal system, with respect to the conventional road transport, a port has to be very flow-through. The major threats here, regard capacity, the efficiency of transhipment and interactions with the other transport modes. In the process of transport planning, the choice of a port affects significantly the route for the further transport to the final destination. A route that is more competitive and attracts a larger quantity of freight, will also achieve a greater social and economic effect in that area. For this reason, this research focuses on the port system and related traffic infrastructure.

Without a systemic analysis, based on the criteria set in order to realise a successful Motorways of the Sea system, it is difficult to define the direction in which ports of a certain area, will (or will not) develop, specialise and associate.

Through research, Croatia, with its maritime ports and maritime system, including ports within the region, has been chosen to test the suggested models. Hence, the identified models have been modified according to the conditions and to the current state of the traffic system in Croatia, In this way, concrete scenarios have been defined and analysed with the previously defined criteria.

While analysing and searching for the optimal solution, it has not been possible to used past research and defined criteria weights, as they do not exist in world literature. It was therefore necessary to define the weight levels, as well as the relations between criteria and sub-criteria. Considering that the implementation of a sustainable Motorways of the Sea system depends on three levels (transport operators, port operators and the State), the criteria weights have been elaborated in relation to the inclusiveness of each of them.

The analysis of the scenario ranking results demonstrates that the decision – that is, which method of implementation for a sustainable motorway of the sea system in the traffic system of the Republic of Croatia – is not a simple and unidirectional decision, but it depends on various elements. In the first place, these are the identified criteria, but also their weights, depending on the influence of the criteria. From the analysis of influence of each single criteria, as well as of all combinations, it may be concluded that, when implementing a sustainable Motorways of the Sea system in the example of the traffic system in the Republic of Croatia, two scenarios (models) can be separated as the optimal choice. These are the model of two ports and the model of regionally grouped ports. Which model to choose, will depend on whose initiative we are dealing with (State or private transport operators) and whether there is a common approach for development.

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These conclusions were generated from the analysis of the current infrastructure condition, of all the included and relevant factors, transformed in criteria and sub-criteria, and from the assignment of weights in relation to the combinations of their influence. The results of the analysis may surely be different, with the modification of any of these elements. In such a combination, models have been analysed for the case of the Republic of Croatia and according to the current infrastructure condition in Croatia. The analysis is definitely applicable in any traffic system in the world, whether it is a national system or a regional system. It may be expected that the same analysis, on the example of another national system, would result in different conclusions, but also that the indicated analysis results, on the example of the Republic of Croatia, can be affected by an intervention on the criteria, sub-criteria, on their weights or by a modification of the infrastructure condition.

REFERENCES

[1] Baird, A.: *EU Motorways of the Sea Policy*, European Conference on Sustainable Goods and Passenger Transport, Kristiansand, 2005.

[2] Baird, A.: *Redefining maritime transport infrastructure*, Proceedings of ICE, Civil Engineering 163, Paper 09-00054, 2010.

[3] Bukljaš Skočibušić, M., Stupalo, V., Žgaljić, D.: Short sea shipping centres: the role of Croatian sea ports // *5th International Scientific Conference on Ports and Waterways "Research and development of ports and water transport" - POWA 2010* / Jolić, Natalija (ur.). Zagreb: Faculty of Transport and Traffic Sciences, University of Zagreb, 2010. 20-28 (lecture, international recension, published paper, scientific).

[4] Brans, J. P., Mareschal, B., Vincke, P.: How to select and how to rank a project: The PROMETHEE method, European Journal of Operational Research, North Holland Publishing Company, 24, Amsterdam, 1986

[5] Commission of the European Communities: *Priority Projects for the Trans-European Transport Network up to 2020* – High-Level Group Report, Office for Official Publications of the European Communities, Luxembourg

[6] Commission of the European Communities: *White Paper Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System,* COM(2011) 144 final, Office for Official Publications of the European Communities, Luxembourg

[7] Commission of the European Communities: *White Paper. European Transport Policy for 2010: Time to Decide*, COM (2001) 0370 final, Office for Official Publications of the European Communities, Luxembourg.

[8] Commission of the European Communities: *Green Paper on the Impact of Transport on the Environment. A Community Strategy for Sustainable Mobility, Communication from the Commission,* COM (1992) 46 final, Office for Official Publications of the European Communities, Luxembourg.

[9] Dundović, Č., Jugović, A., Žgaljić, D.: *Analysis of Croatian ports in respect to Motorways of the Sea implementation*, IMSC 2012 - International Maritime Science Conference, Book of Proceedings, University of Split, Faculty of Maritime Studies, Split, Croatia, 2012.

[10] European Commission, Vademecum on Motorways of the Sea – Article 12bis of the guidelines for the Trans European Transport Network, 2007

[11] Europen Commission, Report on the Motorways of the Sea – State of play and consultation, Commission staff working document, SEC (2007) 1367, Brussels, 2007.

[12] European Commission Communication COM (97) 243 Final

[13] Intermodality and intermodal freight transport in the European Union - A systems approach to freight transport. Strategies and actions to enhance efficiency, services and sustainability, Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions. COM (97) 243 final, 19 May 1997

[14] Jolić, N., Žgaljić, D., Bukljaš Skočibušić, M.: Adriatic short sea shipping development, // *5th International conference on maritime transport "Maritime transport V. Technological, innovation and research"* / Barcelona: Department of Nautical Science and Engineering, Universitat Politècnica de Catalunya, 2012. 1091-1103 (lecture, international recension, published paper, scientific).

[15] Jugović, A., Žgaljić, D., Poletan Jugović, T.: *Model of encouragement for the development of intermodal transport in the Adriatic region, in function of sustainable development,* Seafaring: journal of maritime studies 24, Rijeka, Croatia, 2010.

[16] Saaty, T. L.: How to make a decision: The Analitic Hierarchy Process, European Journal of Operational Research 48, North-Holland, 1990.

[17] Styhre, L.: Capacity utilisation in short sea shipping, Chalmers University of Technology, Department of Technology Management and Economics, Götenberg, Sveden, 2010., PhD.

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