Traffic Flows System Development for Smart City

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Abstract. The work is devoted to the development of an information system, where the movement of vehicles is a central element. Another key element is research and development of theoretical and methodological foundations and mathematical tools for performing all kinds of tasks for managing these flows, improving the transport network and maintaining good quality of the roads. To achieve this, the following questions were raised in this document: analysis of existing methods of solving various problems related to the traffic of a large city; development of a formalized approach to solving this class of problems; development of algorithm for optimization of these tasks; implementation of developed algorithms in the complex traffic management program. As a result, specific practical problems regarding managing the traffic flow of a large city were solved, the adequacy of developed models and algorithms was proved, and the usefulness of their use was shown.

Keywords. Traffic flow management, information system, information technologies, management system, transport network, vehicles, road quality, traffic congestion.

1 Introduction

Transport infrastructure is one of the most important infrastructures that provide the life of cities, villages, regions, regions, and even countries [1-7]. According to the definition, it is a collection of certain objects (enterprises) involved in the construction, repairing, as well as the maintenance of the roads, bridges etc. The transport infrastructure ensures the availability and preservation of transport routes in proper condition. It includes railways, railway stations and stations, highways, public transport, streets, airlines and airports, river routes and ports, seaports, bus stations, tram lines, etc. In recent years, many major cities have completely exhausted the potential of transport networks development. That is why optimal planning of transport

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networks, improvement of traffic organization, optimization of the public, industrial and other route types of transport have become of particular importance [8-15].

Due to the intensive use of infrastructure, the transport sector is an important component of the economy and a common tool used for development [16-20]. A stable, efficient and well-supported transport infrastructure gives urban and rural residents the opportunity to participate in economic opportunities and access to basic services.

2 System Analysis of the Research Object

A goal tree is a structured, hierarchical principle (distributed in levels) of a set of goals of a system, program, plan, in which the general purpose ("the top of a tree") is allocated; subordinate to her subculture of the first, second and subsequent levels ("branches of the tree") [8]. The name of the "goal tree" is due to the fact that the schematically presented this set of goals resembles the inverted tree.

The term "tree" involves the use of a hierarchical structure (from senior to younger), obtained by dividing the general purpose into its subculture. The goal tree method is oriented towards obtaining a relatively stable structure of goals, problems, and directions. To achieve this, when constructing the initial version of the structure, one should take into account the patterns of the formation of the goal and use the principles of the formation of hierarchical structures.

This method is widely used to predict possible trends in the development of science, technology, technology, as well as for the compilation of personal, professional or the goals of any company. A goal tree closely links prospective goals and specific tasks at each level of the hierarchy. At the same time, the purpose of the higher order corresponds to the top of the tree, and below several tiers are located local goals (tasks), through which provides the achievement of the goals of the upper level.

When constructing a "goal tree" its design is based on the method "from general to specific". The termination of the decomposition of the purpose occurs at a time when the subsequent process is inappropriate in relation to the main goal. In general, the structure of the objectives tree is as follows: the root of a tree is a general purpose, formulated in the form of one or two sentences in a natural language. The following levels are aspects of the general purpose, if need be - later examples that can be represented as a hierarchy of sub-targets, and eventually the level of "leaves" of the tree - criteria. The criteria can be either quantitative - that is, measured directly and represented by numerical values with a certain dimension, and qualitative ones - the values of which are obtained from experts and processed by systematic methods.

Accordingly, at the first stage we will form the main, global objective of the system, which has a long-term, strategic nature and is aimed at the introduction and operation of the system. Since the system can have only one main (general) purpose, for this information system it has - management of traffic flows (cities) (Fig.1).

1.1. Quantitative and qualitative transport composition Data collection and monitoring
1.1.1. Number of a camera that meets the set requirements
1.2. Data collection and public transport organization
1.2.1. Optimization of public transport traffic interval
1.2.2. Prompt information on arrival of transport
2.1. Analysis and optimization of traffic lights

2.1.1. Effective functioning of traffic lights
2.2. Collection of road conditions in different weather conditions
2.2.1. The promptness of the call for equipment for clearing roads

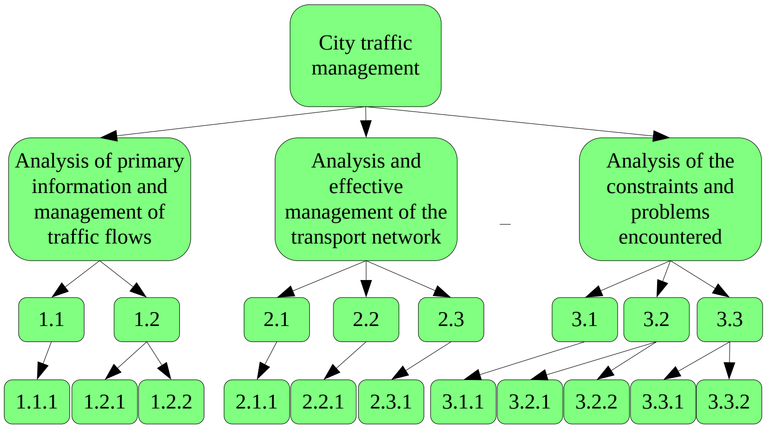

Fig. 1. Goal tree of the information system of traffic flows of a large city

2.3. Roads monitoring
2.3.1. Effective schedules of repair work
3.1. Data collection and raising financial capital
3.1.1. Optimization of tariffs for transport services
3.2. Reporting overview and troubleshooting
3.2.1. The promptness of informing drivers about traffic jams
3.2.2. Optimal congestion routes
3.3. Obtaining and minimizing information from police about violations
3.3.1. The optimal number of police
3.3.2. Maximizing sentencing

The main goal of the development of the main goal is the analysis of the external and internal environment of the system, assessment of its resources and capabilities. At the second stage we will make a decomposition of the main goal of the system for the purpose of the second level (aspects of the general purpose). Formation of the objectives of the second level (aspects) in the directions is in line with the main strategic goal, which should guarantee its implementation. Such aspects in this case are: analysis of primary information and vehicle management, analysis and efficient management of the transport network, analysis of constraints and solving problems. Aspects of general purpose characterize the specialized directions of activity and functioning of the system. Each direction represents a clearly defined sphere of specialized activity of the system. In the third stage, we decompose the objectives of the second level (aspects of the general purpose) in accordance with the specific tasks (sub-aspects of the general purpose). For the first aspect, when decomposing, there are new exits: data collection and monitoring of quantitative and qualitative transport composition, data collection and optimization of public transport; for the second - analysis and optimization of traffic lights, data collection on the condition of highway in different weather conditions, monitoring of the state of roads; and accordingly, for the third, data collection and raising financial capital, an overview of reporting and solving the problem of corruption, receiving information from the police about the violation and minimizing it. At the next stage, the decompositions describe the "leaves" of the tree, which are the criteria for achieving the goal. As shown in Fig. 1 the following criteria for achieving the main goal of the information system of traffic flows of a large city in accordance with the sub-aspects of the general goal are: the number of cameras that meet the requirements, optimization of the interval of public transport, efficiency of informing about the arrival of transport, the effective operation of traffic lights, the speed of calling vehicles for cleaning roads , effective schedules of carrying out of repair works, optimization of tariffs for transport services, efficiency of informing drivers about traffic jams, optimal routes of traffic collapse, optimal number of police, maximization of penalties. The interaction of the system with elements of the environment with sufficient completeness will be reflected within the notation of the DFD (flowcharts) using the context diagram, and the detailing - by constructing the DFD hierarchy of the following levels. Data Flow Diagrams (DFDs) depict the flow of information for any process or system. They use symbols such as rectangles, circles and arrows, as well as short text labels to show incoming and outgoing data, storage points and routes (information transfer) between each destination [9]. These charts can be used to analyze an existing system or create a new one.

The data flowchart may become more detailed by levels. Levels DFD are numbered 0, 1 or 2, and sometimes you can go to level 3 or go beyond its limits. The required level of detail depends on the amount of what they are trying to achieve. The level of DFD 0, also called the context diagram, is depicted in Fig. 2.

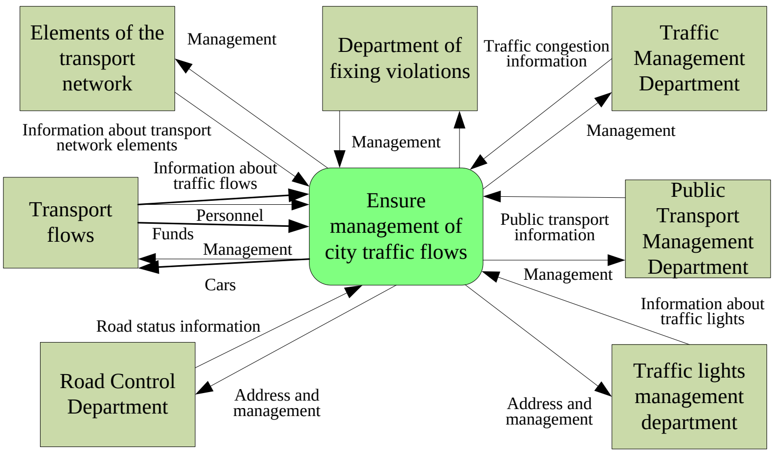

Fig. 2. Context diagram of the information system of traffic flows of a large city

This is a basic overview of the entire traffic information system of a large city to be analyzed and modeled. It is designed for clarity and in order to display the system as a single high-level system, with its interconnections and external objects. The context diagram is easily understood by a wide audience, including stakeholders, business analysts and developers. This context diagram depicts only one main process "to ensure the management of traffic flows (cities)" and the following external entities: "traffic flows", "elements of the transport network", "the department of fixing violations", "the department of control of traffic jams," the department of public management transport "," traffic lights management department "and" road control department ", which will provide stream management. Level DFD 1, shown in Fig. 3, provides a more detailed breakdown of parts of the context chart. Here are the main functions performed by the system, by separating the system of high level on its subprocesses.

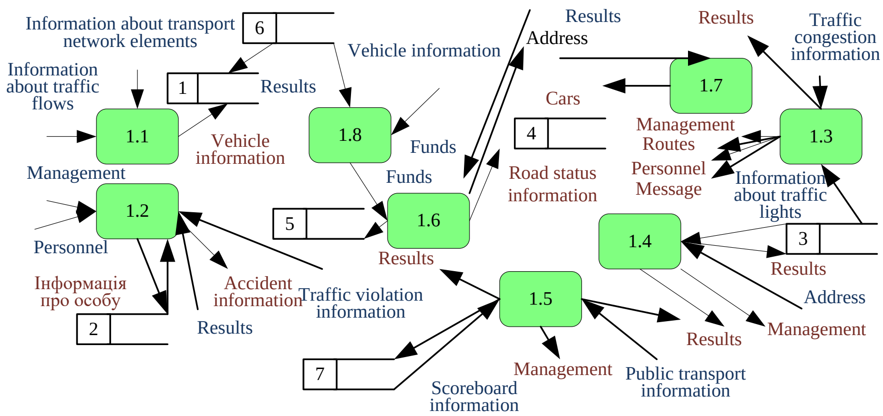

Fig. 3. Flowchart of the data of the first level

Databases:
1 – Vehicle information;
2 – Reporting of violations;
3 – Traffic light information;
4 – Report on repair work;
5 – Cards;
6 – Transport service information;
7 – Information about the characteristics of the scoreboard.
Processes:
1.1 – Collect vehicle information from surveillance cameras;
1.2 – Fix violations;
1.3 – Solve congestion issues;
1.4 – Ensure proper use of traffic lights;
1.5 – Optimize public transport;
1.6 – Check the condition of the roads;
1.7 – Check the weather on the roads;
1.8 – Provide payment for transport services.

From this diagram it is clear that at this stage, according to the standard, there are no new entities, but only duplicates those that were on the context. In addition, there are new processes (subprocesses) and data warehouses.

The sub-processes in this chart are "collect information about vehicles", "fix violations", "solve problems with congestion", "optimize the traffic of public transport", "ensure the proper use of traffic lights", "monitor the state of roads", "conduct road traffic control "and" provide payment for transport services ". In addition, there are 7 data warehouses on the chart: "vehicle information", "transport service information", "violation reporting", "traffic lights information", "table information and characteristics", "maps" and "reporting on conducting repair works". At this stage, the diagram describes in more detail the essence of the system. However, in my opinion, it can be decomposed more in order to describe in detail some of the subprocesses. As a result we get DFD 2 level. DFD level 2 are divides into more parts the 1st level graph. In order to achieve the required level of detail about the functioning of the system, a more detailed description of the system will be required. To begin with, consider the process of "collecting information about vehicles" (Fig. 4).

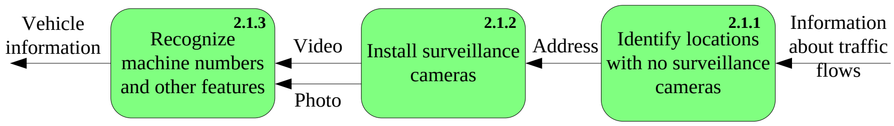

Fig. 4. Detailing the process of collecting information on vehicles

As you can see, the diagram shows new processes: "to determine places with no observation cameras", "to install surveillance cameras", "to recognize machine numbers and other characteristics". The results of these processes will be recorded in the data store "vehicle information", which will be used in the future by the system in the execution of other processes.

Next we decompose the process of "fixing violations" (Fig. 5). We see that in this second level diagram there are new processes: "fixing traffic accidents", "fixing traffic offenses", "delaying the offender", "imposing a punishment", "calling police officers", "calling for ambulance if necessary". The external essence of the "Department for fixing violations" will send information and collect all the results.

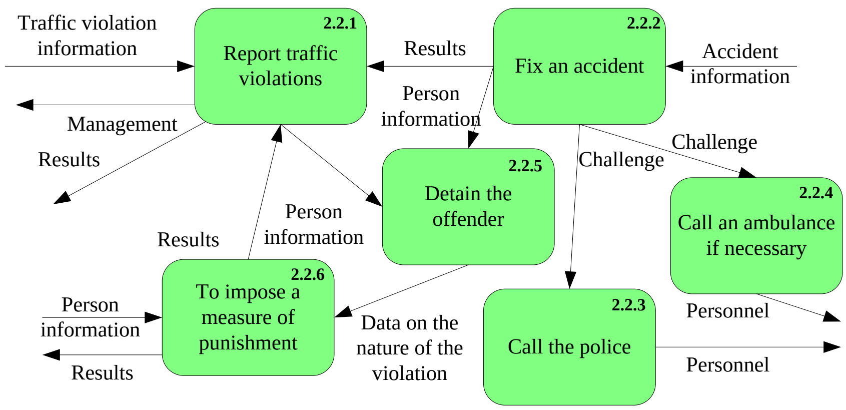

Fig. 5. Detailing the process of fixing violations

And all recorded violations and road accidents with information about place, time, date, person and the actual violation and punishment for it will be stored in the data warehouse "reporting of violations", which the police will also use to review the frequency of relevant events committed by that or another person to determine the penalties for this person. This data storage is depicted on a higher level chart. The process of solving the problem with congestion is extremely relevant and at the same time quite complicated. It includes several subprocesses with much entities and data storage. How this issue will be solved by the information system is shown below (Fig.6).

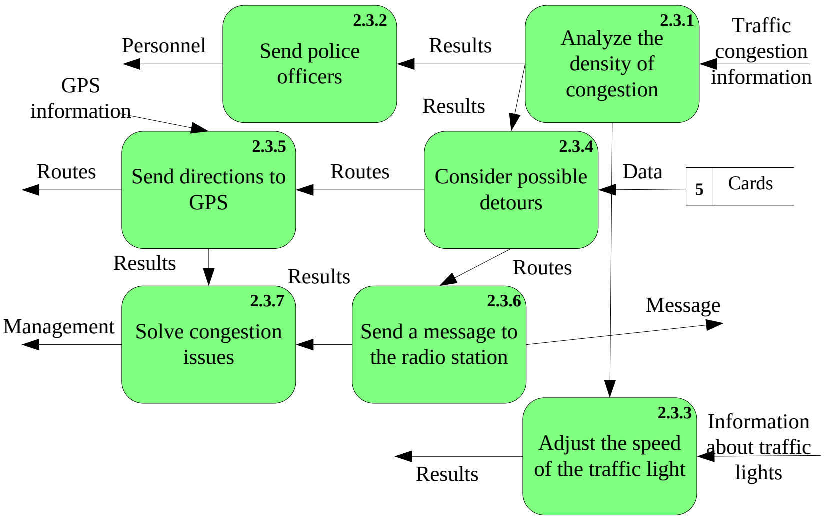

Fig. 6. Detailing the process of solving problem with congestion

When the cameras observe an excessive accumulation of vehicles on one or another section of the transport network, a signal with this information is sent to the traffic control unit. Accordingly, the unit assigns the task of solving this problem to the following processes: "to send police officers", "analyze the density of the trick," "to consider possible options for a detour", which are taken from the data warehouse "maps", "send directions to GPS", "send message on the radio station", "adjust the pace of work of the traffic light "and, of course, "solve the problems with traffic jams"

When fixing the camera of the observation of excessive replenishment of vehicles in one or another department of the transport network, signal with the information is sent to the department of traffic jam management. As a result, he refuses to solve the problem of the following processes: "breaking the bottlenecks", "analyze the integrity", "expand the possible options for exchange", which are displayed with the data warehouses "maps", "dispatch sending to GPS", "sending messages". message on the radio station "," prepare the pace of work of the traffic lights ", usually" solve problems with the traffic jam". If we describe in detail the process of optimizing public transport, then several new processes will appear in the diagram (Fig. 7). Among them: "analyze the population at stops," "determine the required amount of each transport," "determine the required frequency of vehicles," set the scoreboard, "send data with the arrival time on the scoreboard" and "calculate the failure." In my opinion, with the help of these data, the traffic of taxis, trams, trolleybuses and other vehicles people will be much more satisfied, since all possible factors for comfortable movement of people and informed expectations will be taken into account.

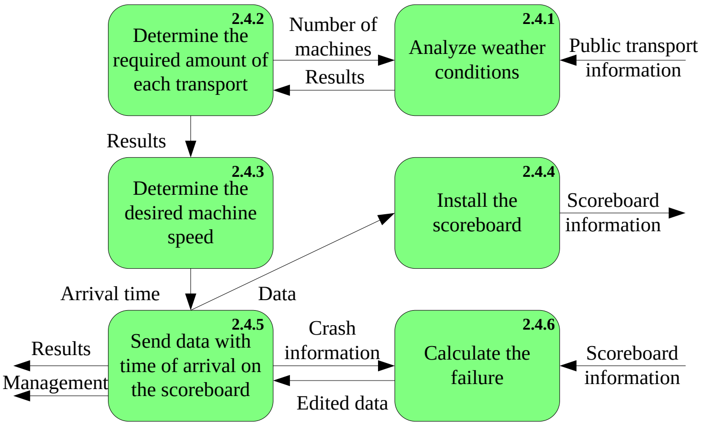

Fig. 7. Detailing the process of optimization of public transport

Next we consider the process of "ensuring the proper use of traffic lights", or rather its decomposition (Fig.8).

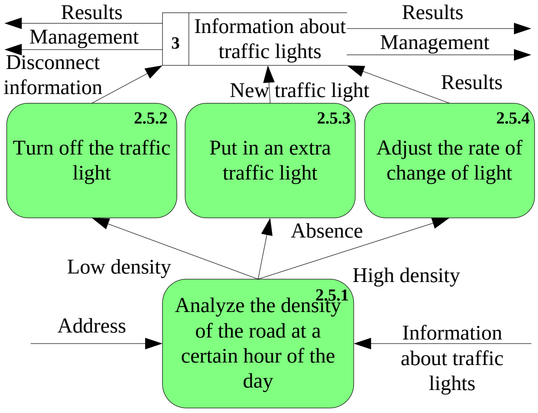

Fig. 8. Decomposition of the process of using traffic lights

Here the managing link is the external essence of the "traffic lights management department". The diagram also shows the processes "analyze the density of the road at a certain hour of the day", as a result of which the following processes will be performed depending on the results: "turn off the traffic light", "put an additional traffic light" or "adjust the light speed". All results of the above actions are stored in the data store "information about traffic lights", which is also used to read current data of a given traffic light and further work with it. Fig. 9 depicts the process of "monitoring the state of roads". This chart is managed by the "road control department", as it provides information about a specific address and requests the processes of "constructing a new road" and "checking the state of the roads." The funds for such actions are partly received as a result of the process of "ensuring payment for transport services". The results of the construction are recorded in the already mentioned card data repository. After checking, if necessary, there is a process of "drawing up a schedule of repairs" and "carrying out repairs", the results of which are reduced to "reporting on the repair work." This data warehouse is also analyzed in the process of checking the state of roads for a decision on the need for the start of repair. The next process, which we will decompose, is "to provide payment for transport services" (Fig.10).

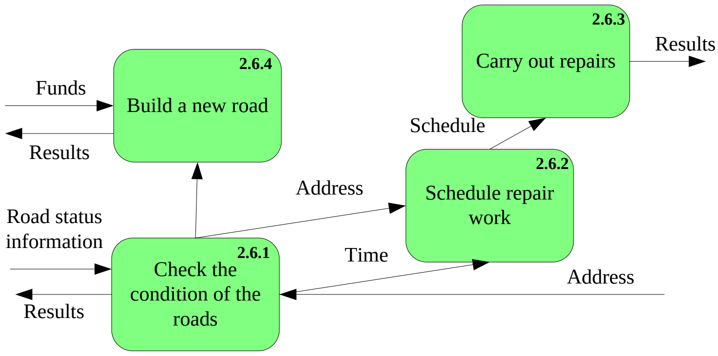

Fig. 9. Detailing the process of monitoring the state of roads

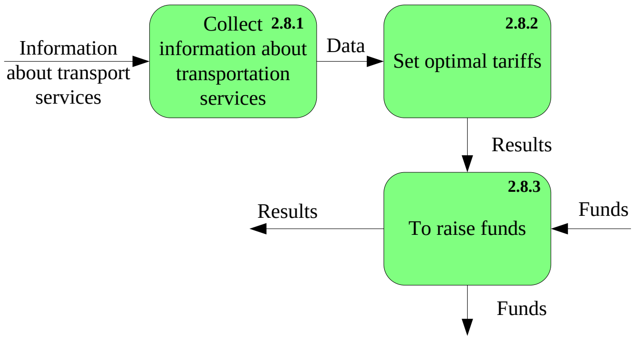

Fig. 10. Detailing the process of ensuring payment for transport services

The processes that perform the function of ensuring payment for transport services: "to gather information about transport services", "to establish optimal tariffs", "to raise funds". Funds are collected from drivers of vehicles, some of which are transported for the construction and reconstruction of roads. All information on tariffs and collected funds is stored in the "transport service information" repository. The final process that we will decompose is to "control the weather on the highways" (Fig.11).

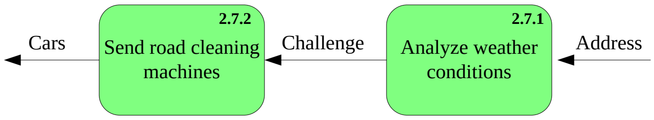

Fig. 11. Detailing the process of monitoring the weather on the highways

The external essence of this process is the "Department of Road Weather Monitoring". The processes in this chart are "to analyze weather conditions" and "send cars to clear roads". In general, the system can be further elaborated to 3.4 and further levels, but going beyond Level 3 can lead to significant complexities as the model may become less comparable and effective. Therefore, at this stage, we will stop.
According to the definition, description and rules, the DFD diagram of the information system of traffic flows of a large city was built, which is a generalized intellectual transport system. Let's take a closer look at what it is.

Intelligent Transport Systems (ITS) are advanced applications that, without the intelligence as such, are aimed at providing innovative services related to different modes of transport and traffic management and allow different users to be more informed and make transport networks safer, coordinated and "smarter" [10]. Intelligent transport systems differ in applied technology, from basic control systems such as automotive navigation; traffic light control systems; container management systems; automatic speed detection for monitoring applications such as video surveillance systems; and more advanced applications that integrate real-time data and feedback systems from a number of other sources such as parking systems and other information systems; weather information, etc. In addition, prognostic methods are developed to make modern simulations progress in comparison with historical data.

3 Building a Hierarchy of Tasks

This information system consists of many tasks that can be represented hierarchically (Fig.12). From the figure, we see that the main task, located at the top of the hierarchy, is "the task of regulating traffic flows." It breaks up into 8 sub-tasks, which, in turn, also have several tasks at their lower levels. Including:

1) "task of collecting information on vehicles", which includes the "task of installing surveillance cameras" and "the task of recognizing the machine number";

2) "task of fixing violations", which is divided into 2 subtasks - "task of fixing violations of traffic rules" and "task of fixing an accident". For them, the lowest level of the hierarchy will be "the task of delinquent offender";

3) the "problem of solving the problem with congestion", which includes the "task of collecting information about the jam" and "the problem of analysis of the density of the flood", which also branch out to "the problem of considering possible alternatives to detour", "the task of adjusting the pace of the traffic light "And" the task of calling police officers ";

4) "task of optimization of public transport", which includes the "task of setting the table" and "task of determining the frequency of vehicles." The latter includes the "task of sending data to the scoreboard" and "task of calculating failures";

5) "the task of ensuring the proper use of traffic lights", which includes the "problem of analyzing the density of the road at a certain hour of the day" and "the task of collecting information about current traffic lights", which also branch out to the "task of turning off the traffic light", "the task of installing additional traffic lights" and "the task of setting the pace of change of light";

6) "task of collecting fees for transport services", which include "the task of collecting information about transport services" and "the task of optimizing tariffs". They in turn, at the lower level of the hierarchy, have a "task of raising funds";

7) "task of monitoring the state of roads", which is divided into "the task of constructing a new road" and "the task of checking the state of roads". The latter also has a lower level of "the task of scheduling repair work" and "the task of repair";

8) "task of monitoring the weather on highways" includes the "task of collecting information on the availability of appropriate equipment" and "the task of weather analysis", which in turn include the "task of sending cars to clear roads".

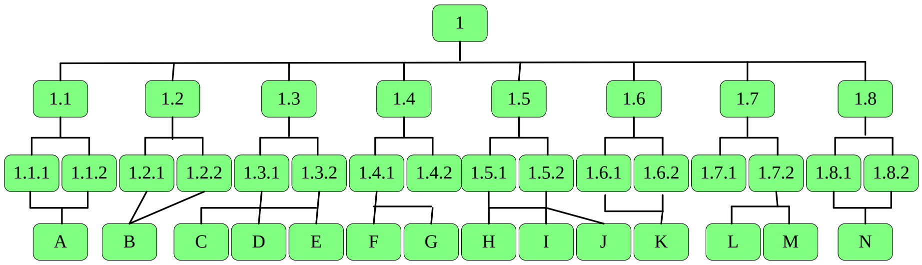

Fig. 12. Hierarchy of tasks of the information system of transport flows of a large city

Tasks:
1 – Management of city traffic flows;
1.1 – Information about vehicles;
1.1.1 – Installation of data collection from chamber storage;
1.1.2 – Machine number recognition;
1.2 – Commit message;
1.2.1 – Fix traffic messages;
1.2.2 – Fixing of an accident;
1.3 – Traffic congestion management;
1.3.1 – Collection of congestion information;
1.3.2 – A real congestion;
1.4 – Optimization of public transport traffic;
1.4.1 – Propose machine speeds;
1.4.2 – Installation of a simple scoreboard;
1.5 – Specially protected light of traffic lights;
1.5.1 – Analysis of the reliability of expensive at a certain hour of acquisition;
1.5.2 – Collection of information about current traffic lights;
1.6 – Complete set of payment for transport services;
1.6.1 – Information on transport services;
1.6.2 – Tariff optimization;
1.7 – Existing roads are observed;

1.7.1 – Construction of a new road;
1.7.2 – Check the condition of the roads;
1.8 – Highway advantages available;
1.8.1 – Information about the equipment that supports these people;
1.8.2 – Analysis of weather data;
A – Separate traffic monitoring;
B – Delinquency delays;
C – Adjusting the speed of the traffic light;
D – Consideration of possible detours;
E – Call the police;
F – Sending data to the scoreboard;
G – Subtraction fence;
H – Turning off the traffic light;
I – The installation of additional bright light;
J – Adjust the light change rate;
K – The collection of rights;
L – Drawing up of graphic repair of works;
M – This repair;
N – The link of road widening machines.

4 Description of the Created Software

Let's launch the program and select the required characteristics. We select the number of cars and press the start button. Let's see how cars ride without starting a congestion drive algorithm (Fig. 13). Next, we will switch to the mode of using the required algorithm (Fig. 14). We see that the paths of some cars differ considerably in these modes, and in the mode with the algorithm traffic is not formed. Now let's consider and compare the timelines of unmanned vehicle fares with initial data and algorithm (Fig. 15).

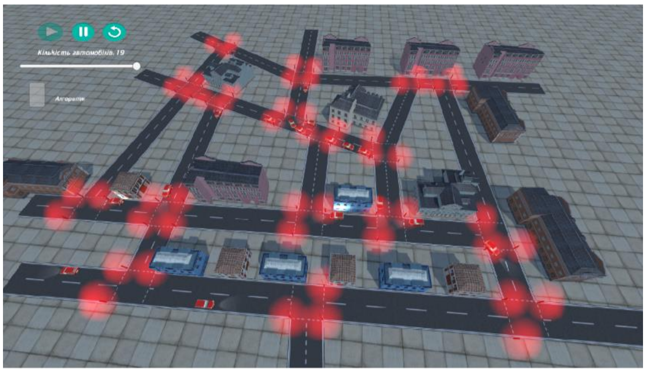

Fig. 13. The movement of cars with the initial data

We see that taking into account the algorithm used, the time of travel of some cars has significantly decreased, and for the rest of the cars remained almost unchanged (difference to 0.5 s). So, the program is workable and the goal is achieved. For this purpose, the most active part of it was chosen, which creates the greatest discomfort for the participants of the traffic movement. In particular, a program implementing one of the methods for solving congestion problems was developed. Motivation of the driver's actions determines the place, time and way of movement. Each driver individually decides whether he needs to go this or that way, or whether he relies on minimizing fuel costs or time. Therefore, to avoid the influence of the human factor on the movement of vehicles, this program works with unmanned cars. When planning a route to your destination, an unmanned car determines the shortest path. However, with obstacles such as traffic jams, this path may cause significant delays. The program is also designed to schedule commuting trains, minimizing the time for which the vehicle will arrive at destination.

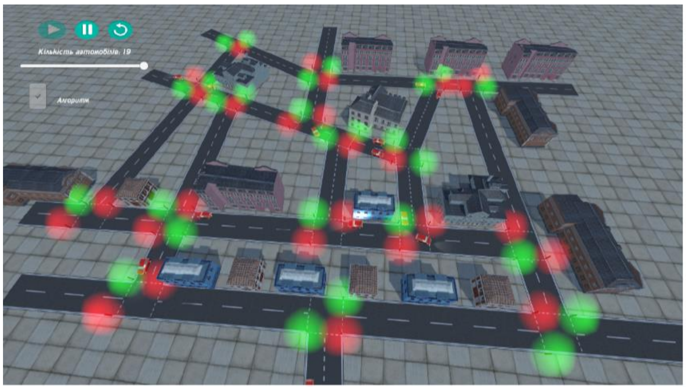

Fig. 14. Movement of cars according to the algorithm

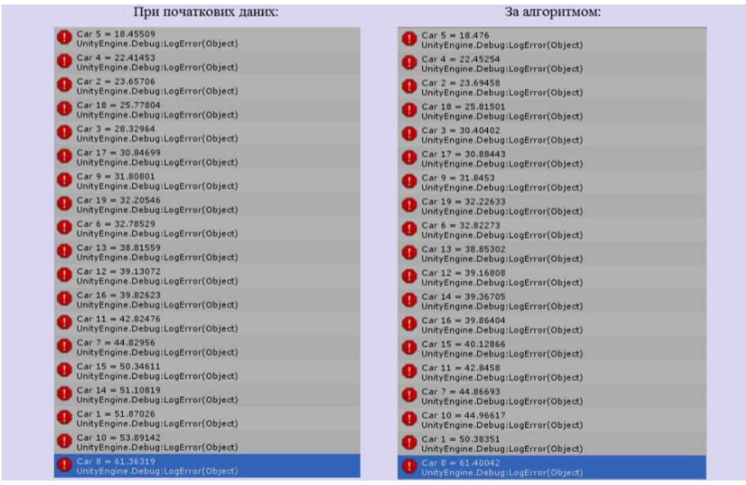

Fig. 15. Time characteristics of travel of unmanned cars

The program works with Unity, where we set the number of vehicles that will move, and the locations of their movement and destination will be read from the statistics stored in the database of the traffic information system of the big city. Then the cars are moving according to the traffic rules, and taking into account the traffic lights. When detecting a significant number of vehicles at an intersection (intersection), the car according to the Dijkstra algorithm is looking for a shorter route, bypassing the overloaded road. Vehicle movement stops when the planned place is reached. The program is called by executing executable file (with extension .exe).

The input data is the number of cars that will move on the map (the starting points and destinations of each of the cars are indicated in Unity) and the choice of motion algorithm or not. The starting point is the actual traffic of cars on the map, which shows the fastest route itself.

5 Conclusion

The work of predecessors was highlighted and issues remained unpublished and those that require further research. Then a systematic analysis of the functioning of the system was performed, the purpose of the system was specified by constructing a goal tree, the main variants of its achievement were given by decomposition to aspects, sub-aspects and criteria for evaluating the quality of implementation. Next, a hierarchy of data flow diagrams was constructed, which, with a sufficient degree of detail, describes the processes of the functioning of the IP, the links between them and the information necessary for the successful operation in the context of the selected type of IP. On the basis of DFD a task hierarchy is constructed taking into account the sequence of their execution. The main characteristics, methods of problem solving, methods of presentation of knowledge, software, system and auxiliaries, which are used in work for construction of mechanisms of choice of the optimal route of a detour passage, are given. The description and analysis of methods for solving the problem with congestion is presented, as well as for the implementation of the C # language and the Unity tool for developing a graphical interface for working with the map and unmanned cars. The composition, structure, content and functions of the developed software and the processes of their joint operation were described. The reference example confirms the working capacity of the development, and the results of the system's operation correspond to the task. As a result of this work an information system was developed, the main element of which is the traffic flows of a large city. The theoretical and methodological provisions and mathematical tools for performing various types of tasks for managing these flows and improving the transport network and supporting the state of roads were also researched and developed.

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