# MODELING OF CRITICAL NODES IN COMPLEX POORLY STRUCTURED ORGANIZATIONAL SYSTEMS[1]

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**Abstract**

A mathematical model of the problem of determining critical nodes in complex weakly structured organizational systems is proposed. The use of graphs to model the relationships between elements of the system is justified. Peculiarities of the phenomenon of criticality in relation to elements, elements and subsystems of a complex weakly structured system are considered. The main aspects of the characteristics of organizational systems, which are significant in terms of criticality of their functioning, are highlighted. The application of expert evaluation in determining the level of criticality of system elements in some aspects is considered. The application of known approaches to the selection of critical elements of the system, in particular, the matrix of responsibility, is substantiated Based on the research, it can be stated that the identification and provision of critical elements of a complex organizational system is an important element in ensuring the functional stability of such a system.

This model can be adapted to the needs of a particular organization, as well as applied in other subject areas. The model is open to improvement and can be focused on dealing with fuzzy data.

**Keywords:**

poorly structured complex organizational system, information security, objects of critical information infrastructure, functional stability, decision making, responsibility matrix, function of belonging to fuzzy set.

## 1. Introduction

With the development of society and technology, attention is paid to the reliability, security and stability of complex organizational systems [1, 2]. Security issues cover not only technical issues but also economic and political aspects. The main purpose of creating a comprehensive security system is to build a system of information security management (ISMS), which will achieve an acceptable level of protection of information resources and provide an acceptable level of guarantee. In this case, the ISMS must ensure the sustainable operation of the facility, timely, reliable and comprehensive prevention of security threats, the functional stability of all subsystems and the information system (IS) as a whole [3,4].

For critical systems, the cost of external audit and certification is extremely high and can reach half the total cost of IS. Therefore, the construction of adequate models of such systems is relevant and requires comprehensive research.

At the same time, effective management and compliance with regulatory requirements requires addressing issues related to [5]:

- increase in total IT costs;
- selection of service providers and management of the procedure of attracting third-party service providers and their acquisition;
- the emergence of growing complex risks associated with the use of IT, in particular such as network security risks;
- the need to optimize costs using, as far as possible, standardized, rather than specially designed approaches;
- • increasing the level of development and consistent adoption of such methodologies as the CobiT® standard, the IT Infrastructure Library (ITIL), a series of standards related to

information security ISO 27000, ISO 9001: 2000, Capability Maturity Model® Integration (CMMI) and others.
- the need for organizations to evaluate the results of their activities on the basis of comparison with generally accepted standards and performance of similar companies.

For critical systems, the cost of auditing and attesting to "best practices" is extremely high. At the same time, in the sector of information security services, including critical information infrastructure (CII), there is a wide variety of approaches to the implementation of ISMS as an element of ISMS and possible methods of assessing the level of information security.

The analysis of compliance of SUITs and ISMS implemented on the basis of "best practices" is based on a risk-oriented approach.

Risk in this context means a potentially possible event in the field of cybersecurity, which may lead to a violation of the basic properties of the protected information. According to "best practices", it is considered that the process of cybersecurity risk management should be consistent with the overall risk management process of the enterprise and should be applied both in the process of creation and in the process of operation of ITMS and ISMS.

The objects of corporate security of the organization are management technologies, members of the organization, financial resources, material values, production technologies, business processes, information resources, etc. One of the essential features of organizational and technical systems is the a priori existence of subjectivism - both in their construction and at all stages of their functioning. Ensuring the reliable operation of the information security system is an essential and imperative task for any organization. With increasing competition at all levels - from competition in business in market conditions to confrontation between states - the problem of reliability of the ISMS requires the development of new models and the generation of new methods to ensure its reliability.

Issues of reliability of complex security require special attention, for example, in the design of decision support systems and the development of technology to ensure the reliable and sustainable operation of such systems [3, 6].

One of the essential indicators of the level of system functioning is functional stability [4, 7]. Functional stability is the ability of a system to perform its functions during a given time interval under the influence of the flow of operational failures, intentional damage, interference in the exchange and processing of information, as well as in case of errors of stuff service [8, 9].

The main properties of complex systems that characterize their functional stability are reliability, survivability, fault tolerance. Functional stability in some way combines all the above characteristics. The problem considered in this paper can best be described by applying the concept of functional stability, the implementation of which is achieved through the use of different types of redundancy, by redistributing resources to compensate for the consequences of emergency situations [10].

The purpose of this work is to study the situation of ensuring the stable operation and protection of information, at a given level of definitions, a complex poorly structured organizational and technical system.

In order to quickly assess the quality of operation of such systems a model for determining the integrated indicator of the quality of system operation is necessary.

This integrated quality indicator should adequately reflect changes in the structure of the system and quality indicators of the functioning of its elements. At the same time, it is promising to use the methodology of introspective analysis of subjective components of the system and expert decision-making technologies to solve the described problem [11].

The purpose of the study can be considered achieved when an integrated indicator is defined, which adequately characterizes the state of functional stability of the system and sensitively responds to changes in the composition of the system and the structure of the relationships of its elements.

To achieve this goal it is necessary to develop a mathematical model to ensure a sufficient level of functional stability of a complex poorly structured system based on information about the presence of damage to its elements and subsystems. It is also necessary to provide options for duplication of functions, operational interchangeability of subsystems, to solve the problem of integrated assessment of the quality of the system and the choice of its optimal configuration to increase functional stability.

This will be facilitated by models for determining the state of execution of functions by elements and subsystems, the choice of options for interaction between elements and subsystems in order to maximize the integrated quality of execution of functions by the system as a whole. In addition, it is necessary to build a model that will reflect the system's response to various types of environmental influences and changes in the state of the system elements.

## 2. Formulation of the problem

Suppose you set some set of indices of protection functions that the system should provide. We will assume that such functions $n$. Denote the set of all functions performed by the system through $A=\{a_1,...a_n\}$, $J=\{1,...,n\}$.

Note that the number of functions of a complex system can be hundreds and thousands of units. Functions performed by different elements of the system are not duplicated, ie $n=\sum_{i\in J} n_i$ - each function in the system is unique: $A^{i_1} \cap A^{i_2} = \varnothing, i_1, i_2 \in J$, where $\varnothing -$ the set is empty.

The relationship between functions and the sequence of their execution is given by the binary relation $B$, which is a subset of the Cartesian product $A \times A$. The binary relation $B$ is constructed taking into account the sequence of functioning of some organizational and technical system and reflects the logic of solving the problems facing the system and its elements. Moreover, the performance of each function of the system is provided by some element of the system $e^i, i \in I=\{1,...,k\}$, and can be performed by some other element $e^j, i \neq j,\ i, j \in I,$ - in the General case with different degrees of quality - that is, the system has a redundancy.

We will consider that the tool of an estimation of quality of performance of functions of protection of system is constructed.

That is, the current level of performance of each function is heuristically determined, evaluated or measured by special subsystems and the potential quality of performance of each function by other elements is evaluated, for example, on a 100 percent scale.

It is possible to take into account:

- losses in duplicate performance of functions by system elements;
- there are options for replacing elements by applying staff recruitment in the case when modeling a system of personnel management, maintenance, restructuring, etc .;
- the cost of replacing each element of the system is known;
- you can assess the probability of a successful search for a new element of the system and the quality of its functions;
- it is possible to estimate the costs of the adaptation procedure, its support by special services, the duration of the adaptation period, the costs of interaction with related interconnected elements and units, the effectiveness of adaptation, etc .;
- also determines the time for adaptation of a new element of the system, the dynamics and quality of adaptation;
- you can make a reliable forecast - the mathematical expectation of the period of operation of the system element;
- you can estimate the market value of each function, etc.

## 3. Application of graphs in modeling organizational systems

The management system, regardless of its purpose and nature of origin is the basic basis of any organizational system. Any organizational and technical system can be represented as a model of an undirected graph. The vertices of the graph are the elements (subsystems, links, nodes) of the system, and the edges are the connections between them.

The class of problems considered in this paper is characterized by the following conditions:

- given an oriented graph $G(V,E)$ of large dimension;
- the number of vertices of the graph $|V| \sim 10^3$;
- the number of edges of the graph $|E| \sim 10^4$;
- on the vertices of the graph a set of characteristics of system elements is set;

- on the edges of the graph are given the characteristics of the sequence and intensity of relationships between elements of the system;
- characteristics of vertices are set in the form of cost of performance of function of elements of system and in the form of level of quality of their performance;
- estimates of the quality of functioning of the vertices of the graph are given;
- it is necessary to calculate the value of the objective function when changing the links in the column locally;
- the decision maker (DM) can influence the type of the objective function and the relationships between the vertices of the graph;
- restrictions are set on the construction of variants of changing the vertices and edges of the graph.

## 4. The concept of criticality in organizational and technical systems

The priority tasks that will be assigned to the ISMS of the organization of prevention or prevention of critical incidents of information (cybersecurity) and, as a consequence, the collapse of the functioning of the organizational and technical system as a whole [12].

Production systems are one of the subsystems of larger organisational system, which has many other subsystems. Each organisational subsystems are independent at the same time they are interdependent. They are independent in the sense that each functional subsystem has its own objectives and goals and at the same time they are functionally related with the other subsystems of the organisation.

Critical elements or subsystems of the organizational and technical system are key elements in ensuring the sustainable operation and interaction of all its elements and subsystems.

In a weighted graph, you can select the elements of the system, the impact of which will have critical negative consequences for the entire model of interaction of system elements. In the composition of any system there are critical elements, the violation of which generates synergistic effects of destructive processes. Such elements or subsystems are called systems with critical infrastructure.

Systems with critical infrastructure contain a significant number of interconnections between elements and connections with other systems. Breaking any of these bonds can potentially lead to a "chain reaction" effect.

A system with critical infrastructure can be represented by a critical network architecture, interconnected by certain elements (objects) that are part of it. In addition, it should be noted that the number of the most important among such objects is limited to their small number.

The centers of gravity in each sector of critical infrastructure are formed in accordance with different laws: technical, economic, social, managerial, etc., which allow a set of previously unstructured elements to form critical networks. In many cases, the emergence of such centers of gravity leads to the self-organization of the network and the possibility of its effective operation.

Critical organizational subsystems, in which failures can lead to significant economic losses, physical destruction or threats to human life, require special attention to their functional stability.

To increase the functional stability of critical subsystems, infrastructure stability, quality of maintenance, adequate motivation system, staff productivity and timely detection of failures, control and diagnostic systems are used. Failures in control systems lead to the most serious consequences in failures of critical subsystems. The requirements for security systems in critical systems in terms of security are becoming more stringent. At the same time, with the development of computer technology, more and more responsible functions are being transferred from human to computer technology.

Under these conditions, the problem of improving the security of control systems is becoming increasingly important [4].

A critical element or subsystem is a system whose operating parameters affect the efficiency and effectiveness of all processes in the system.

Every organization has critical elements and subsystems. It is possible to identify groups of critical elements and identify or evaluate the relevant criticality characteristics. Particular attention in such systems should be paid to elements whose operation is critical to the functioning or even existence of the system as a whole. It is advisable to introduce signs of criticality, exploring the features of critical elements. The main features of critical elements in hierarchical organizational systems are:
- they have appropriate levels of access and authority for exclusive action;

- critical elements have resources that are an order of magnitude larger than normal elements, and the authority to manage them;
- the activity of critical elements is provided with much higher costs than the activities of other elements;
- in addition to the direct impact on the functioning of other elements, subsystems and the system as a whole, critical elements have a significant indirect impact;
- indirect impact of critical elements on the system as a whole may be higher than direct impact;
- critical elements, as a rule, carry out functional management of elements which do not have direct subordination to them;
- critical elements have a significant impact on both the elements of the lower level of management and the elements of the upper levels of the hierarchy of the organizational system;
- when the failure of critical elements, significant losses are suffered not only by their subordinate elements, but also the system as a whole;
- critical elements are characterized by a greater number and variety of connections - they are usually nodal elements;
- critical elements have a significant impact on different levels of management and different subsystems;
- a characteristic feature of critical elements is a significant and direct impact on the elements of the lower level of management.

When modeling the features of critical elements, it is also necessary to provide options for duplication of functions, operational interchangeability of subsystems, to solve the problem of integrated assessment of the quality of system operation and selection of its optimal configuration to increase functional stability. This will be facilitated by models for determining the state of execution of functions by elements and subsystems, the choice of options for interaction between elements and subsystems in order to maximize the integrated quality of execution of functions by the system as a whole. In addition, it is necessary to build a model that will reflect the system's response to various types of environmental influences and changes in the state of the system elements.

## 5. Expert assessment in modeling critical elements in organizational and technical systems

The basis of most of the known research on the development and justification of detection methods, as well as the search for objects with critical infrastructure is the methodology of expert analysis.

Its basis is the methods of expert evaluation. However, the use of peer review methods is known to address the problem of finding available source information on the potential damage to a "critical infrastructure reference facility". However, the methods of expert evaluation have a number of disadvantages:
- the reliability and reliability of the research results depend on the competence of experts;
- subjectivity of the methods used;
- the complexity of the procedure for collecting information;
- the need for highly professional specialists to conduct the survey.

Critical systems have a complex network of dependencies that allows you to analyze the level of interconnected dependencies between different aspects of a critical system, which can be useful in planning or getting a true picture of how criticality is organized in complex organizational and technical systems. This will identify bottlenecks in a complex system, the points at which a critical subsystem (or set of subsystems) is vulnerable in one way or another.

One of the approaches to increase the functional stability of the system is the selection of critical elements (links, subsystems) of the organizational system. At the same time it is necessary to consider features of critical elements at their modeling. In particular, one of the approaches may be to offer erosion of functionality in subsystems in order to diversify risks.

It should be noted that critical elements of the system are characterized by motivating and demotivating effects. In addition, through these nodes are significantly more voluminous flows of information. Therefore, the absence of nodal points to a greater extent affects the functional stability of the system.

## 6. The structure of the organizational technical system

The peculiarity of the system being modeled is that it has a hierarchical structure, and the functions performed by the elements of the system are not independent. In the general case, the following components should be taken into account when modeling the system:

- the level of control of the element, the subordination of the element to the highest element in the hierarchy, subordinate elements of the lower level, functional subordination, functional subordination, basic functions, the level of quality of functions, related functions, the quality of related functions;
- establishing hierarchical links between the elements of the system and determining the levels of influence of one element on another or the absence of such influence;
- the level of influence of the element on the unit to which it belongs;
- the level of influence of the control element of the unit on other units;
- the level of influence of the control element of the unit on the system as a whole;
- the functional subordination of elements has a significant impact on the interaction between units;
- create a register of positions with double and triple subordination;
- create a register of functions in the interaction between departments: cross-functional business processes.

The decision maker can choose one or more options for managing the system to ensure its functional stability:

- zero quality of the function is allowed, ie it is allowed to decide that the function for some time or forever is not performed by the element and the system as a whole;
- ignore the need to perform a function and thus change the structure of the system;
- replace an element of the system or some of its functions with another element, realizing that the quality of functioning of the entire system will be lost;
- the decision on the critical performance of certain functions or the admissibility of non-performance of certain functions is taken at a higher level of management.

This paper does not describe the architecture of the system: we note only that it has a hierarchical structure and there is an interdependence of units. These aspects need further study and will not be considered in this paper.

For further reseach of the functional stability of the system, it is also promising to describe and optimize business processes, which include detailed relationships between the elements of the system and the functions they perform.

Business processes are a sequence of functions (activities, works, operations, procedures, tasks, actions) that are regularly repeated and reflect the purpose of the organizational system. But such research is not the purpose of this work.

## 7. A model for identifying critical elements of a complex organizational system

The critical part of any infrastructure or critical element (node, link, subsystem) of any system are such elements, the functioning of which depends on the state and performance of the system as a whole or most of it. Since the scheme of interaction of elements can be represented by a multiconnected graph, the critical nodes of such a graph are those nodes of the graph, the failure of which will lead to a decrease in functional stability or loss of connectivity of a significant number of nodes of the graph. Other elements of the system that are not critical will be called linear[13].

To analyze the data and decide on the level (class, indicators) of the criticality of the elements should monitor the data, which can be divided into several aspects [14] (groups, directions, layers, blocks). It is advisable to consider the following aspects of the elements of a complex poorly structured system, which are the vertices of a graph that simulates a specific system in some subject area:

$\alpha_1 -$ impact on resource systems;

$\alpha_2 -$ flows controlled by the element;

$\alpha_3 -$ influence on decision-making in the system;

$\alpha_4$ – a set of managerial influences on the elements of the system;

$\alpha_5$ – the need to respond to many requests that are processed by the system;

$\alpha_6$ – managing access to important aspects of the system;

$\alpha_7$ – the set of edges of the graph, which provide information to the vertices;

$\alpha_8$ – a set of graph edges that model decision-making procedures in the system.

To determine the quantitative characteristics of the vertices of the graph, it is necessary to consider the corresponding incidence matrix or Kirchhoff (Laplace) matrix. The weight of the rib can be considered the number, importance and complexity of documents that run on management and other flows.

Consider in more detail the indicators (characteristics, parameters) that can be included in some aspects.

When determining the impact of a system element on its resources, it is necessary to carry out an in-depth analysis of system resources [15, 16]:

$\alpha_{11}$ – human (labor) resources;

$\alpha_{12}$ – financial resources;

$\alpha_{13}$ – material resources;

$\alpha_{14}$ – intangible resources;

$\alpha_{15}$ – information resources.

The greater the impact of an element on these resources at the strategic, tactical or operational level, the more critical it should be. The criticality of an element in the context of the first aspect is calculated by a formula, the values of which can be set tabularly or analytically $f_1\left(\alpha^i_{11},\ldots,\alpha^i_{15}\right)$, where $i,\ i \in I$ – the indices of the elements of the system.

It is also necessary to analyze the flows that control the element, or have a significant impact on them:

$\alpha_{21}$ – financial flows;

$\alpha_{22}$ – material flows;

$\alpha_{23}$ – information flows;

$\alpha_{24}$ – service flows.

To determine the level of criticality of the elements should consider the integrated flows to which the elements of the system are related. Quantitative indicators characterizing the flows affected by each element of the system are calculated by the formula $f_2\left(\alpha^i_{21},\ldots,\alpha^i_{24}\right)$, $i \in I$. It is clear that the value of this function for some elements can be zero: $\exists i,\ i \in I:\ f_2\left(\alpha^i_{21},\ldots,\alpha^i_{24}\right) = 0$.

The overall impact of each element on decision-making in the system (aspect $\alpha_3$), the intensity of the set of management influences (aspect $\alpha_4$), the need to respond to many requests processed by the system (aspect $\alpha_5$) and the level of authority of the element to manage access to important aspects of the system (aspect $\alpha_6$) be determined, for example, on ordinal scales by peer review.

The characteristics of the set of graph edges that provide information nodes (aspect $\alpha_7$) and the characteristics of the set of graph edges that model decision-making procedures in the system (aspect $\alpha_8$) can be determined on a quantitative scale by analyzing formalized business processes that describe the elements of the system.

A feature of modeling the criticality of elements of a complex system is that the data used to analyze and compare criticality are measured or evaluated on different scales. Aggregation of data combined into aspects for each element of the system can be done in different forms:

- some discrete levels of criticality are defined;
- the function of belonging of criticality of an element to a fuzzy set is calculated;
- the intervals of values of criticality of each element are defined;
- fixed values of criticality of elements in metrized scales are calculated.

A special aspect that characterizes the elements of the system, which are represented by the vertices of the graph, may be the RACI responsibility matrix [17], which provides a description and coordination of the structure of responsibility for the implementation of work packages in projects and business processes.

This matrix is a form of describing the distribution of responsibilities for the implementation of work on a project or business process, indicating the role of each element of the system in their implementation.

The RASI responsibility distribution matrix is used in various management doctrines - functional, process and design. They are a convenient tool for dividing responsibilities between the elements of the system: Responsible, Accountable, Consulted, Informed. Based on the analysis of these roles of elements in the system, we can conclude that each element is critical.

Eeach criterion, a number of subcriteria can be defined, linked to the various capability levels. The criteria are [5]:

Successful execution of those process practices for which the organizational structure (or role) has accountability or responsibility (an A or an R, respectively, in a responsible-accountable-consulted-informed [RACI] chart)

- Successful application of a number of good practices for organizational structures, such as:
- Operating principles
- Composition
- Span of control
- Level of authority and decision rights
- Delegation of authority
- Escalation procedures
- Successful application of a number of organizational structure management practices.

Given the model described above, it can be concluded that the impact of the critical element on the functional stability of the organizational system should be at least one or more orders of magnitude greater than the impact of linear elements.

## 8. Modeling of decision-making situations

In the process of functioning in real conditions, the decision-making situation described in the problem statement in an idealized form can differ significantly from the normative one. For example, in the case of a large organization, there are always employees who are currently on sick leave, on vacation, on business trips, absent for unknown reasons, officially issued time off, fired for various reasons, violating labor discipline, absent due to force majeure. major circumstances, are adapted and therefore do not perform tasks well enough, there are conflict situations, demotivated employees, etc. [18,19]. All these reasons can be assessed, heuristically determine the current level of performance of each task and assess the quality of performance of each task, for example, on a 100 percent scale.

When building a model of decision-making situations, the following heuristics should be considered:

Heuristics E1. When the load on the system element exceeds the normative quality of performance of all functions that it performed, it decreases linearly or according to another law, the formalization of which can be carried out by introducing additional heuristics.

Heuristics E2. The quality of functional stability of the system decreases in the absence of a critical element, because one of the management functions is control, and the influence of the manager, which is often a critical element, on the elements of the unit is more significant than the influence of other system elements.

## 9. Modeling the distribution of functions between system elements

It is clear that the substitution of functions between the elements of the system can be done according to the matrix of relationships only between those elements that can perform these tasks, according to their qualifications, available certificates, and so on. In this case, the following heuristics should be considered.

Heuristics E3. When performing functions that are not normative for a system element, the quality of execution of these functions by those elements that are intended for temporary execution of functions is set individually for each case.

Heuristics E4. The functions of a critical element cannot be fully replaced or cannot be replaced in principle - there are no elements in the system that could functionally replace some functions of a critical element.

Heuristics E5. If it is necessary to solve an element of the system of additional functions, there is a situation of overloading the element and therefore reduces the quality of functions:

- performance of own normative functions, for example, to the level of 90-95%;
- performing additional functions taking into account the heuristics of E3.

## 10. Conclusions

The paper proposes a model for determining the critical element of the organizational system.

Also substantiated:

- the built model of definition of critical elements;
- the admissibility of expert assessment in determining the level of criticality of some aspects of the functioning of the elements;
- the proposed approach to determining the integral level of criticality of the elements of a complex system.

Based on the research, it can be stated that the identification and provision of critical elements of a complex organizational system is an important element in ensuring the functional stability of such a system.

This model can be adapted to the needs of a particular organization, as well as applied in other subject areas. The model is open to improvement and can be focused on dealing with fuzzy data.

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