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Structural and functional simulation of interaction in the field of aviation safety by using matrices

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ABSTRACT

Purpose: The conducted research was aimed at constructing a structural and functional model for the interaction of bodies providing aviation safety during crisis management.

Design/methodology/approach: The methods of mathematical simulation and the graph theory, the methods comparison and formalization have been applied to study the process of interaction between the bodies assuring aviation safety. Using methods of the linear algebra allowed constructing a mathematical model for the functional structure of the interaction process that contains description of this process by the main methods of interaction.

Findings: It has been proved that the interaction process has a certain functional properties that reflect the functional relations between the modes of violator actions, the modes of using the response forces and the modes of interaction. A structural and functional model of interaction in semantic, algebraic forms and in the form of graphs has been created. using typical operations with incidence matrices, the possibility of obtaining the physical interpretation of the simulation results within the introduced algebra of functional structure models has been justified.

Research limitations/implications: Discusses interactions between the bodies that assure aviation safety and at the same time, the possibility of a crisis situation is taken into account.

Practical implications: The developed models allow reflecting the current state of the functional system and the elements of the process of interaction rather completely. It makes a structural and functional analysis of interaction possible and allows defining the priority directions of its organization, simulating the options and methods of interaction in solving relevant tasks by the bodies that assure aviation safety.

Originality/value: That allowed not only describing the formal relations between the methods of interaction and interacting units, between the interacting units and the modes of violator actions, but also considering the influence of the interaction process on the current state of the functional system.

Keywords: Aviation safety, Structural and functional model, Incidence matrix

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Safety is the primary task for state regulation of aviation activity and airspace use. The tragic event of September 11, 2001 has irrevocably changed the attitude to the national security standards not only in the United States of America but in all civilized countries of the world. That induced the various agencies operating in the aviation industry to complete revision of the developed aviation safety standards [1,2], as well as to creation of appropriate research programs [3].

However, most of the discussions on regulating such an important area of activity as aviation safety relate to interpretation of key economic issues that are critical for assessing various regulatory methods [2]. At the end of the day, it became clear that efficiency of the aviation safety system would not be achieved only through introduction of new protection technologies. The success depends on the aviation safety improvement projects that explore interaction of people, processes and technologies [3].

Aviation safety assurance at the aviation activity subject is entrusted to the Aviation Security Service. When conducting activities at the territory of the airline to counter the acts of unlawful interference, the Aviation Security Service interacts with military units and law enforcement agencies of special purpose. Besides, the emergency rescue and fire protection service is involved in minimizing the consequences of crisis situations caused by terroristic acts or sabotage.

Thus, in the event of a crisis situation, the responsible management body is to organize joint measures for its settlement. Organization of joint measures consists of the stages of preliminary and immediate (operational) preparation for their holding. The main problem in organizing joint measures is definition of priority directions of interaction and the most effective mechanism of interaction between all structural subdivisions of interaction subjects. Determination of priority directions of interaction between different formations in the event of a crisis situation should be done in the process of developing organizational and managerial decisions at the preliminary stage during development of the relevant planning documents. This requires scientifically substantiated recommendations for making such decisions. Lack of scientific justification makes conducting relevant research necessary.

The basic principle of establishing a safety management system is the ability to control risks revealing, to identify and optimize control measures. An active method for managing aviation safety is threats revealing and analysis. The paper [4] presents an analysis of methods for assessing security threats in air transportation. It has been shown that statistical methods, probabilistic methods, methods of a failure tree creation, the method of mathematical simulation, the use of artificial neural network, threat risk assessment, etc. can be used to assess threats. Herewith, the presentation of various approaches to threats assessment is fragmentary. It may be caused by limitation in using these methods due to complexity of the aviation system and the random nature of dangerous events occurrence. But the issues of assessing the ability to withstand common threats and consequences, the study of the relations between the threat and the effective countermeasures system remain unresolved.

In paper [5], a methodology for qualitative and quantitative assessment of the safety risk for civil aviation and the process of its assessment based on concepts of threats, criticality and vulnerability has been developed. Correlation in determining the risk level has been underlined. It has been shown that the developed methods allow analysing the critical objects protection system, assessing the importance of the measures for enhancing safety against efficiency, etc. At the same time, the organizational aspects of counteraction to external threats (acts of unlawful interference) are left out of focus.

Analysis of aviation safety and a set of measures to protect aviation against unlawful interference are presented in paper [6]. The importance of a conceptual approach to airport security is highlighted, and the psychological, legal and organizational aspects related to preparation and functioning of the airport security system are indicated. It is suggested to apply a new approach to analysis of the airport security threats, indicating the possibility of adapting the methods used in aviation to the methods of determining anti-terrorist security. The essence of this method is to apply two analytical methods to determine the potential objects of a terrorist attack. One of the methods is based on analysis of the object characteristics, the other – on synthesis of factors that affect the potential level of threat (CARVER method). At the same time, the issue of defining an effective system of countering threats was left out of consideration. And this, as a rule, is associated with solving multi-criteria optimization tasks.

In the paper [7], the considerations on coping with the problem of solving optimization tasks in the field of aviation safety are given. It is shown that most of such tasks are related to solving the conflict situations. The theory of conflict gives an analytical solution only in the simplest cases. An alternative approach in this field consists in using the capabilities of the decision making theory and the heuristic algorithms. However, the issue of describing the problem situation remains unresolved. This should be explained by certain difficulties of formalization and mathematical interpretation of the subject area in view of its specifics.

Thus, it should be noted that scientists are trying to solve the problem of enhancing aviation safety by different scientific approaches and methods, but the issue of simulating the interaction between the subjects of aviation safety generally stays unconsidered.

The above mentioned issues were considered during research in the field of the interaction between the subjects assuring aviation safety.

The paper [8] presents the results of scientific research on the interaction of the National Guard of Ukraine with the State Service of Ukraine for Emergency Situations. The structural and functional model of the interaction between the governing bodies and the subdivisions has been developed. This model differs from the existing ones by description of the research object done using the mathematical apparatus of the graph theory, which allows defining the possible variants of interaction. Scientific novelty is to determine the relations between tasks, functions and structural subdivisions. But the problematic issues of describing the ways of interaction remained unresolved. After all, it is the methods that describe the nature of interaction in a practical plane. Besides, this model does not take into account the influence of the relations between functional elements on the actual state of the interaction process. One of the ways of eliminating disadvantages is development of a model that will allow physical interpretation of the corresponding functional relations.

In the paper [9] an innovative model of interaction between the State Special Transport Service with other subjects of national security in different conditions has been developed. The practical basis for development of specific mechanisms of interaction, definition of common and specific forms and methods of action has been shown. At the same time, novelty of the model is reduced to introduction of indicators and criteria for assessing the interaction effectiveness. And the general approach takes into account the same methodological basis for creating a structural and functional model. Thus, the issue of describing the functional relations of the interaction subjects stayed out of consideration.

The opposite view of the existing problem is given in the paper [10]. It is stated that simulation of social processes always involves the possibility of an error which rather significantly affects the reliability of the result, thus, there is a high probability of getting a wrong decision. The forms, methods and directions of interaction can be determined by analysing the relevant legal and regulatory documents and the experience of practitioners. In this case, it is reasonable to speak about the structural and semantic model of interaction. In its turn, the decision made by the manager as to organization of interaction is purely rational (by developing the criteria and analysing the alternatives).

Based on the analysis of scientific works, it should be mentioned that the system of aviation safety assurance in its functions, composition and structure belongs to the class of complex systems. Functional and informational descriptions of such systems are associated with different aspects of behaviour in different conditions. Interaction must be considered an integral part of the aviation safety management system. Despite all the diversity of modern approaches to improving the management mechanisms, the ideas related to the structural and functional characteristics of the management system are laid as the basis. Therefore, simulation of the interaction of the subjects assuring aviation safety has been poorly investigated. Thus it can be argued that studying relevant issues with the use of mathematical modelling methods is reasonable.

The conducted researches were aimed at creating a structural and functional model of the interaction between the bodies assuring aviation safety during crisis situation settlement. The structural and functional analysis of the corresponding model done using mathematical methods should determine the priority directions of its organization, rational options and methods of interaction in performance of common tasks.

At present, the methods of mathematical modelling are becoming increasingly important for the study of complex systems [11-13], hazardous processes [14-16] and expensive [17-19].

To achieve the set goal, the following tasks have been solved:

- to formalize the process of interaction between the bodies assuring aviation safety in a way that will enable studying the subject of research by the methods used in the study of the interaction between the subjects that assure state security;
- to create a structural and functional model of interaction in semantic, algebraic forms and in the form of a graph;
- using the linear algebra apparatus, to create a mathematical model for the functional structure of the interaction process, which will allow making mathematical description of the process by the basic methods of interaction.

2. Materials and methods of investigations

In order to solve scientific problems and achieve the set goal, a systematic approach was used within which the appropriate research methods were applied. Applying the methods of generalization, comparison and formalization made it possible to reflect the process of interaction between the bodies assuring aviation safety in the form of a formal system similar to the previously studied system of interaction between the subjects that assure state security. Applying the methods of mathematical simulation and the graph theory allowed constructing a structural and functional model of interaction in semantic, algebraic forms and in the form of a graph. Using methods of the linear algebra allowed constructing a mathematical model for the functional structure of the interaction process that contains description of this process by the main methods of interaction.

3. Results of the interaction process simulation and discussion

In order to solve the set task, certain assumptions will be made. Let the group of forces (the reaction forces) consisting of the structural subdivisions of the subject of aviation activity and the subdivisions of the security forces be created during the crisis situation for its settlement. The leading role in detecting and suppressing the acts of unlawful interference into the activities of the enterprise is given to the Aviation Security Service and the dedicated law enforcement agency of special purpose, respectively. Then we will nominally consider the process of interaction between the aviation safety forces with the forces of the authorized state body of special purpose respectively, including all structural subdivisions involved into elimination of the crisis situation.

The system of interaction is considered to be a relevant complex system in which a set of elements interconnected and interacting with a common idea function in order to solve a specific problem under given conditions. Then the development of a structural and functional model of interaction gives the opportunity to replace the set of relations with the corresponding quantitative values without describing the process of the system elements functioning. Herewith, if necessary, the dependence of these values on the situation can be given in the form of a table or an analytical expression. And evaluation of these dependencies by formal indicators and criteria determines the list of variants of interaction in performing a specific task under conditions of a certain type of crisis situation.

Analysis of the tasks and functions of the structural subdivisions of the Aviation Security Service (ASS) and the special-purpose body (SPB) allows identifying those that can participate in settlement of the crisis situation and, as a result, should establish an interaction for more effective solving of the set tasks. Therefore, the list of structural subdivisions, tasks and functions, as well as the list of typical crisis situations should form inputs for development of the model.

Let us assume that the initial composition of forces of the interacting sides and the typical crisis situations in the conditions of which these forces operate are known. Then, using the approach defined in the paper [20] we will form a structural and functional model of interaction with the general characteristics presented in Table 1.

Thus, the model represents a total of six sets (two SI), where the connections between the elements of one SI form the structural and functional bases of tasks of every SI, and the elements of two SI are connected by structural, functional and structural and functional bases of interaction:

a) the set of the ASS structural elements – $S_i=\{u_1\}$, where $u_1=1,\ldots,r_1$ – the number of the ASS structural element;
b) the set of the SPB structural elements – $S_j=\{u_2\}$, where $u_2=1,\ldots,r_2$ – the number of the SPB structural element;
c) the set of the ASS functional elements – $F_i=\{k_1\}$, where $k_1=1,\ldots,p_1$ – the number of the ASS functional element;
d) the set of the SPB functional elements – $F_j=\{k_2\}$, where $k_2=1,\ldots,p_2$ – the number of the SPB functional element;
e) the set of the ASS tasks – $G_i=\{g_i\}$, where $i=1,\ldots,m$ – the number of the ASS task;
f) the set of the SPB tasks – $G_j=\{g_j\}$, where $j=1,\ldots,n$ – the number of the SPB task.

Table 1.
Characteristics of a structural and functional model of interaction

Components of a structural and functional model		Definition
Component	Mathematical expression	
Structural elements	S_u, $u \in R$	Functional subdivisions which form the group of forces, where R is the set of structural subdivisions of a separate subject of interaction
Functional elements	f_k, $k \in P$	Modes of the functional units action, where P is the set of modes of action of a certain subject of interaction
Structural and functional elements	$sf_{uk}=s_u \cap f_k$, $u \in R$, $k \in P$	Pair combination of the structural and functional elements
Structural basis	$S_{Б}$	A set of structural elements that are part of, or can be formed as part of the subjects of interaction (SI)
Functional basis	F_B	A set of modes of action (functional elements) that can be used by SI
Structural and functional basis	SF_B	A set of modes of action (functional elements) that can be used by every structural element of SI
Independent fulfillment of its tasks		
Let the task to be fulfilled be presented as a set $G=\{g_1,g_2,\ldots,g_q,\ldots,g_d\}$		
Functional basis of a task	F_q	A set of modes of action to be used in fulfillment of a specific task g_q
Structural basis of a task	S_q	A set of the structural elements of SI to be used in case of fulfilling a specific task g_q
Structural and functional basis of a task	SF_q	A set of the structural and functional elements that are supposed to be used in fulfillment of a specific task g_q
Under the condition of independent fulfillment of its tasks, each subject of interaction functions in its structural $(S^{(SPB)},S^{(ASS)})$, functional $(F_B^{(SPB)}, F_B^{(ASS)})$ and structural-functional $(SF_B^{(SPB)}, SF_B^{(ASS)})$ bases		
Fulfillment of tasks in interaction		
Let the task to be fulfilled by the Aviation Security Service (ASS) and the special-purpose body (SPB) by presented as the sets $G^{(1)}=\{g_i^{(ASS)}\}, i \in I=\{1,2,\ldots,I,\ldots,m\}$ i $G^{(2)}=\{g_j^{(SPB)}\}, j \in J=\{1,2,\ldots,j,\ldots,n\}$		
Structural and functional space	$SF=SF_B^{SPB} \otimes SF_B^{ASS}= =\{sf_{uk}\}$ $u \in R$, $k \in K$	The general form of the structural and functional bases of two SI expressing the structural properties and interaction of the elements
Structural basis of interaction	$B^s=\{B_1^s,B_2^s,\ldots,B_r^s\}$	Total sets of the structural elements of SPB that every structural element of ASS is reasonable to interact with
Functional basis of interaction	$B^f=\{B_1^f,B_2^f,\ldots,B_p^f\}$	Total sets of the SPB modes of action defined for each ASS mode of action, and when they are applied by various interaction subjects, interaction between them is reasonable to be organized
Structural and functional basis of interaction	$B^{sf} = SF_B^{(ASS)} \cup SF_B^{(SPB)}$	Integration of the structural and functional bases of interacting SI

The formed structural and functional model of interaction in course of a crisis situation settlement can be represented as an unoriented graph $G=(V,E)$ (Fig. 1), where V is the set of the graph nodes corresponding to the number of the system elements, E is the set of edges corresponding to the number of relations between the system elements.

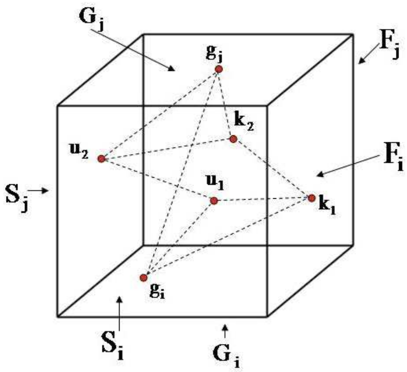

Fig. 1. The graph of the structural and functional model of interaction: S_i – the set of the ASS structural elements (r_1); S_j – the set of the SPB structural elements (r_2); F_i – the set of the ASS functional elements (p_1); F_j – set of the SPB functional elements (p_2); G_i – the set of the ASS tasks (m); G_j – the set of the SPB tasks (n)

Introduction of the elements of the graph theory allows reflecting consistency of the formal model, visualizing the established relations between the participants of the crisis situation settlement process. Besides, the graph apparatus gives an opportunity to describe the interaction process using mathematical methods.

Thus, a model that can be used during structural and functional analysis of the interaction between the bodies that assure aviation safety has been considered. Research of the interaction to the appropriate model is reasonable to be carried out on the variants of interaction, which are understood as one of the possible combinations of two elements of the structural and functional interaction space to achieve the tasks for the specific circumstances.

Let's consider how one can describe the structure of the interaction process using the above approach to creation of a structural and functional model.

In practical terms, the nature of interaction of the response forces to the crisis situation can be described in four main ways or the following combination: interaction per tasks; interaction in space; interaction per time; interaction per ways of accomplishing tasks. Such a statement is based on analysis of the axiomatic foundations of the theory of interaction [21]. Each way of applying forces can correspond to its specific mode of interaction or their combination. When making a decision the manager should find such modes of interaction $S=\{S_i\}$, $i=\overline{1,...,n}$, that would ensure the maximum of the efficiency indicator with the corresponding modes of the violator actions $V_j=\{v_j\}$, $j=\overline{1,...,m}$ under various conditions of the information environment [22].

Thus, the interaction process has a certain functional structure which reflects the functional relations between the modes of violator actions, the modes of using the response forces and the modes of interaction. The mode of interaction is to be understood as the series and the order of implementing certain techniques, forms of action of the reaction forces subdivisions during joint use.

Then, with the purpose of mathematical description of the process of interaction between the reaction forces, it is reasonable to use the main modes of interaction as a foundation for creating a formal system, in which the form will be taken as a special subject of study regardless of the content.

The model for the functional structure of the interaction process is understood as formal (symbolic) description of the elements of this system (modes of interaction, interacting subdivisions ($U=\{u_q\}$, $q=\overline{1,...,k}$), modes of violator actions) and the formal interrelations between them. Let us confine ourselves to considering only such essential properties of the structure of the system as a list of subdivisions, the modes of interaction and the modes of violator actions, availability and characteristics of the formal interrelations between them. Then such a model can be represented as a final oriented graph, in which the listed nodes correspond to subdivisions, the modes of interaction and the modes of violator actions (quantity – final). The edges of the graph will correspond to the existing connections between these nodes. Herewith, every edge of the graph is oriented from the mode of the violator actions to the response force subdivision and from the subdivision to the mode of interaction, having the appropriate length ("loading"). Further on, the length of the edge for a simpler graph will be taken as equal to one if there is a formal bond, or to zero if there is no bond. The concept of "loading" also includes the content of the number of links between the nodes. The scheme of such a graph can be displayed using a flat model that has the edges with zero length and the nodes that are not illuminated if correspond to the inoperable nodes (Fig. 2).

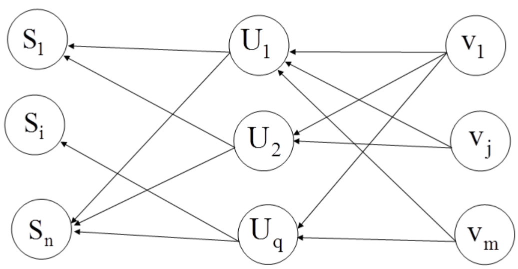

Fig. 2. Example of a graph of the model for the functional structure of the interaction process

For displaying the properties of formal bonds it is reasonable to assign each edge of the graph reflecting the structure of the interaction process with the corresponding quantitative characteristic. This represents the mathematical expectation of the need for such a connection, depending on the information situation, and assumes that the length of each edge of the graph is determined by this quantitative characteristic. To determine the appropriate characteristic for the graph node, it is enough to provide a numbering that will reflect a similar characteristic. Such approach allows not only reflecting the structure, but also researching the properties of the system depending on its structure.

Representation of the model for the functional structure of the interaction process in the form of a graph (which is understood to mean any set of nodes connected in some definite way) is sufficiently clear and allows us to clearly view the physical content of the interaction processes in the systems with the appropriate structure. However, there are cases where the number of possible variants of the use of the violator forces, and, as a result, of the own forces, is sufficiently large, or when there is a need for transformations of the functional structure of the interaction process. Then, the work with the graph of the model gets significantly complicated and there is a need to move to an adequate mathematical model of the functional structure.

It is known that with a sufficient equivalence for the tasks of studying organizational systems being solved, the model for the functional structure of the interaction process displayed with the help of a marked orientation graph can be replaced with a mathematical model. The appropriate model is displayed in the form of an ordered set (table, matrix) of numbers that specify a mutually unambiguous correspondence between the numbered graph nodes and their interrelation (the graph edges). If considered by the convenience of solving further problems, it is reasonable to represent such a model as a matrix of the nodes incidence. Then the numbers of the matrix lines will correspond to the numbers of the violent actions, the column numbers – to the numbers of the modes of interaction, and the elements at the rows and columns intersection will take the value of the length of the graph edge connecting the nodes. A partial example of a model is such a description, where the length of the graph edge takes the value of one if there is a formal connection between the mode of interaction and the mode of violator actions, and the value of zero in the opposite case.

Let us consider a general case, where there are m modes of violator actions and n modes of interaction between the response forces. Then it becomes possible to consider the simulation space as a certain set (union or cross) of the n-dimensional space of the modes of violator actions and the m-dimensional space of the modes of interaction between the response forces.

With such an approach to creating an incidence matrix, each of its lines can be considered as n-dimensional vector of relations derived from the mode of violator actions by a number corresponding to the number of the given line. Moreover, this vector will be determined in the space of the modes of interaction, where it sets the appropriate "coordinates" of the mode of violator actions for the space. Accordingly, each column of the incidence matrix can be considered as m-dimensional vector of relations directed to the mode of interaction with a number that corresponds to the number of the column. This vector will be defined in the space of the modes of violator actions, where it sets the "coordinates" of the mode of interaction in the set of the possible modes of the violator actions. To illustrate the above mentioned, let us consider an example of an unspecified incidence matrix A in the form of

$$A = \begin{Vmatrix} a_{11} & a_{12} & .. & a_{1n} \\ a_{21} & a_{22} & .. & a_{2n} \\ .. & .. & .. & .. \\ a_{m1} & a_{m2} & .. & a_{mn} \end{Vmatrix}. \tag{1}$$

In this example, the vector line $\overline{A}_{1n}=|a_{11},a_{12},...,a_{1n}|$, which is an integral part of the matrix A, represents the set of relations of the ith mode of violator actions with all n modes of interaction between the response forces. At the same time, each vector column reflects the connections of a particular mode of interaction with m modes of the violent actions, for example, for the second mode of interaction the vector of its connections with the mode of violator actions will look like $\overline{A}_{m2}=|a_{12},a_{22},...,a_{m2}|$.

Thus we can construct a clearly binary orthonormal matrix, where each element of the incidence matrix takes only the value of 1, if there is a connection between the modes of violator actions to the mode of interaction, or only the value of 0, if there is no such connection [23].

But the person who makes the decision on organizing the interaction may have inaccurate initial information. In view of that, in the future, when developing the theory similar to a clearly orthonormal incidence matrix, it is expedient to consider the inexplicitly orthonormal matrix of incidence of the modes of violator actions and the modes of interaction. In this matrix, the degree of consistency is set in the range {0.1} by the value of the normalized consistency coefficient, which takes 0 when there is no formal connection, or 1 when there is a stable (clear) connection. When there is a connection, but it is "unclear" (the analogue of such a coefficient is probability of a formal connection between the mode of the violator actions and the mode of interaction between the reaction forces), an intermediate value is set.

Thus, the developed mathematical model allows rather complete reflection of the current state of the functional structure and the elements of the process of interaction. But the practice of studying the structure of the interaction process, the graph of which is presented in Figure 2, requires an additional task to be solved. Thus, the above presented mathematical model describes the current state of the functional structure and the elements of the interaction process in its final phase. It does not describe formal relations between the modes of interaction and the interacting subdivisions, between the interacting subdivisions and the modes of the violator actions.

In order to take into account these connections and the influence of the functional structure of the interaction process on the current state, it is necessary to extend the definition of the mathematical model of the functional structure by introducing the corresponding operations on the incidence matrices that reflect it.

Therefore, the mathematical model of the functional structure is now on understood as a description of the essential elements of this structure and the relations between them expressed in the class of abstract mathematical objects and the relations between these objects. Moreover, such a model will be correct if correct rules of conformity are established connecting the real physical objects (the model original) and relations between them with the corresponding mathematical objects and relations.

Applying the decomposition approach we will construct the corresponding incidence matrices for the graphs presented in Figure 3, which, when combined, give a graph of the model of the functional structure of the interaction process (Fig. 2).

Then the incidence matrix A for the graph pictured in Figure 3a will have the dimension $[m \times q]$, where m is the number of the modes of violator actions, q is the number of subdivisions of the response forces. The incidence matrix B for the graph pictured in Figure 3b will have the dimension $[k \times n]$, where k is the number of subdivisions of the response forces fulfilling the interaction, and n is the number of the modes of interaction. $k=q$ in the unified functional structure being considered. This means that the matrices A and B correlate. Correlation of the matrices A and B means that the vector rows a_i and the vector columns b_j have the same number of projections.

That makes possible scalarizing these vectors, and the result of such scalarizing equals to the sought-for element c_{ij} of the matrix C arising as a result of the matrix multiplication of the matrices A and B:

$$c_{ij} = \vec{a}_i \cdot \vec{b}_j = \sum_{k=1}^{q} a_{ik} \cdot b_{kj}. \qquad (2)$$

The resultant matrix C will have the dimension $[m \times n]$ and describe the interconnection of the elements in the functional structure of the interaction process.

Thus, using the standard incident-matrix operations and the available methods of linear algebra, one can obtain a physical interpretation of the simulation results within the framework of the introduced algebra of functional structure models.

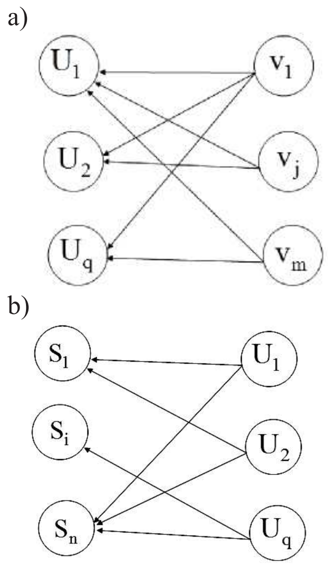

Fig. 3. Decomposition of the graph of the model for the functional structure of the interaction process: a – a graph describing the relations between the subdivisions of the response forces and the modes of the violator action; b – a graph describing the relations between the subdivisions of the response forces and modes of interaction

The obtained results are an attempt to improve the system of aviation safety by developing scientifically substantiated recommendations for making the management decisions on organization of interaction between the structural subdivisions that counteract unlawful interference.

The study of the interaction mechanism is based on the ideas related to the structural and functional characteristics of the management system. Applying the methods of generalization, comparison and formalization made it possible to present the process of interaction between bodies assuring aviation safety in the form of a formal system similar to the previously studied system of interaction between the subjects that assure state security. Such an approach ensures proper research of the mechanism of interaction between the relevant structural subdivisions of the security forces on a single scientific and methodological basis.

The system of interaction is considered to be a relevant complex system in which a set of elements interconnected and interacting with a common idea function in order to solve a specific problem under given conditions. Development of a structural and functional model of interaction gives the opportunity to replace the set of relations with the corresponding quantitative values without describing the process of the system elements functioning. Further researches of this model should be aimed at studying the dependencies of these values from the situation, and at evaluation by formal indicators and criteria.

Therefore, introduction of the elements of the graph theory allows reflecting consistency of the formal model and makes possible description of the interaction process using mathematical methods.

It has been proved that the interaction process has a certain functional structure that reflects the functional relations between the modes of violator actions, the modes of using the response forces and the modes of interaction.

The physical interpretation of the simulation results was obtained using typical operations with the incidence matrices and the available linear algebra methods. This allowed not only describing the formal connections, but also considering the impact of the interaction process on the current state of the functional structure.

Herewith, it is necessary to outline the issues that are left out of focus and need research. Thus, the research results on the process of interaction between the troops (forces) show that it is a complex dynamic phenomenon characterized by availability of both deterministic and random components. The coincidence factor in the process of interaction is regular as to its nature, which means that this factor is a distinctive property of the process being considered. It is demonstrated in changes in the state of interacting forces and means, in the emerging need for applying and restoring of interaction between them. Besides, the coincidence factor is caused by the different structures of the initial information about the place and the modes of violator actions. Considering that, there are interesting prospects for further research that should answer the questions of how to handle the unclear information, or how to choose an effective mode of interaction. The methodology of researching these issues should be based on the main provisions of the fuzzy sets theory, the expected utility theory, the methods for solving multi-criteria selection tasks, etc.

4. Conclusions

1) The process of interaction between the bodies assuring aviation safety has been formalized. The chosen method of formalization allowed studying the subject of research with the help of methods used in the study of the interaction between the subjects that assure state security.
2) A structural and functional model of interaction has been formed in semantic, algebraic forms and in the form of a graph. The model represents an aggregate of six sets: structural elements, functional elements and the tasks of two subjects of interaction. In the developed model, the relations between the elements of one subject form the structural and functional bases of the tasks set for each of them, and the elements of two subjects are bound by structural, functional and structural and functional interaction bases.
3) A mathematical model for the functional structure of the interaction process has been developed. A mathematical apparatus of linear algebra was used to describe the process of interaction per basic modes. That allowed not only describing the formal connections, but also considering the impact of the interaction process on the current state of the functional structure.

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