The task to determine the composition of forces to deter the enemy from starting aggression, that is, to prevent the hot phase of a military conflict, refers to poorly structured problems in the presence of significant uncertainty. This leads to the application of the methodology of system analysis in solving the task. The set of deterrence forces to defeat the enemy is considered as a complex military system, which is the object of this study.

To determine the composition of the enemy's deterrence forces from unleashing armed aggression, this paper reports a devised methodology. The procedure criterion is the effectiveness of deterrence, which is determined by the required ratio of the combat potentials of the aviation of the opposing sides at the end of hostilities.

According to the methodology of system analysis, the procedure is based on the formation of options for the composition of enemy forces and the composition of deterrence forces, assessing the effectiveness of their use during hostilities.

The effectiveness of the use of forces of opposing parties is assessed by using the method of iterations and methods of queuing theory.

Based on the results of the effectiveness assessment, the selection of options for the composition of the deterrence forces is carried out, for which the condition for ensuring the necessary ratio of the combat potentials of the aviation of the parties at the end of hostilities is met. The rational version of the composition of the deterrence forces from those selected is determined by using the taxonomy method, which has made it possible to solve the problem under study. The rational option determines the combat potentials of the components of the deterrence forces, which correspond to the number of units in their composition.

The above methodology should be used by state and military authorities when planning the creation of enemy deterrence forces against unleashing armed aggression.

The application of the procedure is shown in an illustrative example

Keywords: armed aggression, composition of deterrence forces, systematic approach, taxonomy method

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DETERMINING THE DETERRENCE FORCES COMPOSITION TO PREVENT THE UNLEASHING OF ENEMY AGGRESSION BASED ON THE PRINCIPLES OF SYSTEM ANALYSIS

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1. Introduction

The most important and complex task that states solve in order to ensure military security is to deter a possible enemy from unleashing armed aggression.

To this end, measures are taken that are systemic, complex in nature, and combine political, economic, informational, military, and other measures. However, the main role in deterring a possible enemy belongs to the military measures that determine the combat composition of the Armed Forces (AF), capable of inflicting unacceptable damage on the enemy when repelling armed aggression, which will force it to abandon the use of ~~military~~ armed force. The complexity of determining the composition of the Armed Forces to deter a possible enemy, first of all, is due to the unforeseen use of methods to resolve armed aggression, the uncertainty of forces and means that can be involved in warfare. Justification of the necessary combat composition of the Armed Forces to deter the enemy from unleashing armed aggression is carried out by state and military authorities, that is, the results of the study are necessary for practice.

In accordance with the principles of modern military art, the beginning of armed aggression can be considered an air offensive operation by the enemy. To counter such an operation, heterogeneous forces and means should be used to form an enemy deterrence system, which consists of ground, sea, and air components. The basis of the enemy's deterrence system is aviation and air defense forces, which are given the main attention. Given the uncertainty of the enemy's actions in an air offensive operation, in accordance with the principles of system analysis, the determination of the composition of the deterrence forces should be carried out according to the variants of their composition. To select a rational version of the composition of the deterrence forces, it is necessary to apply the method of multi-criteria analysis.

Therefore, the study on determining the composition of the enemy's deterrence forces from unleashing armed aggression in the face of uncertainty of its actions is relevant.

2. Literature review and problem statement

The most studied is the question of determining the required composition of troops (forces) of the type of armed forces for military (combat) operations. Work [1] gives the methodology for substantiating the required composition of aviation in the strategic direction; [2] – the quantitative and qualitative composition of anti-aircraft missile forces; [3] – the composition of the grouping of air defense forces. Nevertheless, the enemy's deterrence forces must have a variety of composition, that is, consist of formations of all types of armed forces.

In [4], the expediency of using the principles of system analysis, consideration of the totality of forces and means for warfare as a complex system is justified in the planning of operations. In determining the composition of deterrence forces as a complex system, it is necessary to consider alternative options for their composition, which should be used in determining the composition of deterrence forces. Nevertheless, the issues of choosing a rational option are not considered.

The choice of a rational version of a complex system in a multi-criteria formulation of the problem on the basis of convolutions of indicators according to the iterative procedure is considered in [5]. Nevertheless, the use of this method does not make it possible to obtain a balanced composition of the elements of the system in terms of indicators.

Work [6] outlines the methodology for comparative assessment of the combat potentials of military formations and the balance of forces of the parties in operations. The use of combat potentials of military formations is appropriate in determining the balance of enemy forces and deterrence forces. The task of determining the rational composition of forces for warfare was not set.

The method of multicriterial analysis of alternatives (Multi-Objective Optimization Ratio Analysis, MOORA), given in [7], is used in two stages: at the first stage, the analysis of alternats is carried out according to the additive convolution of normalized indicators, at the second – by the distance to the reference point. Thus, two priority series of alternatives are built and then they are compared. It should be noted that the use of two approaches in determining the priorities of alternatives in one method contributes to the validity of solving the problem. However, there is no formal mechanism for combining the obtained priority series to determine the best alternative in the article, and there are no approaches to determining the importance factors of indicators. This is due to the provision of decision-makers with a combination of the priority series obtained to determine the best alternatives.

Work [8] reports an improved method of MOORA, called MULTIMOORA, a multipurpose decision-making method. The method involves the use of initial data in the form of membership functions to fuzzy numbers of a triangular form, for the determination of which expert methods are used. Therefore, it can be used during the ranking of alternatives, for the characteristics of which experts use linguistic terms, which is problematic in determining the composition of the enemy's deterrence forces.

The integrated method for evaluating alternatives MCDM (Multi-Criteria Decision Making), given in [9], uses the MACBETH (Measuring Attractiveness by a Categorical-Based Evaluation Technique) method to determine the weights of criteria, and the EDAS (Evaluation based on Distance from Average Solution) method to rank alternatives. The definition of criteria weights is based on pairwise comparisons using a semantic ordinal scale. Ranking of alternatives is carried out by distances from an average solution that does not always provide the choice of the best alternative. In determining the rational composition of the deterrence forces, it is more expedient to compare the options to carry out relative to the reference version.

Work [10] provides a methodology for substantiating the necessary combat composition of forces to prevent the enemy from winning in the air. The combination of heterogeneous means operating in the airspace is considered as a system of defeating enemy troops and objects. As a procedure criterion, a given ratio of the combat potentials of the aviation forces of the parties at the end of hostilities is taken. However, the methodology does not provide for the use of multi-criteria methods for comparing alternatives, which does not make it possible to determine a rational version of the composition of forces for actions in the air. The use of the taxonomy method for choosing a rational version of the combat composition of the enemy's deterrence forces is given in [11]. However, the paper does not provide analytical dependences to determine the losses of the combat potentials of the parties, which should be used in assessing the ratio of the forces of aviation to the parties at the end of hostilities. In addition, in works [10, 11], the question of justification of the criterion of the effectiveness of deterring the enemy remained unresolved.

All this suggests that it is expedient to conduct a study on the development of methodological provisions for determining the composition of the enemy's deterrent forces from unleashing armed aggression.

3. The aim and objectives of the study

The purpose of our study is to devise a methodology for determining the composition of the enemy's deterrent forces from unleashing armed aggression. The presence of such forces will ensure the futility of the enemy's solution of interstate contradictions by armed force.

To accomplish the aim, the following tasks have been set:

– to determine the criterion of the effectiveness of deterring the enemy from unleashing armed aggression;

– to decompose the enemy's deterrence system morphologically in order to take into account the mutual destruction of means during hostilities;

– to develop a general structural scheme for constructing a methodology for determining the composition of the enemy's deterrence forces;

– to derive analytical expressions to determine the relative losses of combat potential during hostilities and the balance of forces of the opposing sides;

– to determine the rational composition of the deterrence forces.

4. The study materials and methods

Most military scientific and pragmatic problems in the field of construction and preparation of the Armed Forces for use, in particular the task of deterring a possible enemy from unleashing a military conflict, are problems that are characterized by significant uncertainty. The main methodological tool for the preparation and justification of solutions for such problems is system analysis. The basis of system analysis is the general theory of systems and a systematic approach, which involves the development of methods and procedures for solving poorly structured problems in the presence of significant uncertainty by the variant method. Grouping troops in the combat composition of deterrence forces can be seen as a complex system.

The system of deterrence of the enemy is understood as a set of forces and means of armed struggle, which are in certain relations and ties and form a certain integrity and unity and are designed to prevent the unleashing of armed aggression by a possible enemy.

The forces and means of armed struggle of the deterrence system must ensure the creation of a group of troops (forces), which, in terms of combat capabilities, is capable of inflicting unacceptable damage on the enemy, which predetermines the futility of unleashing armed aggression.

The effectiveness of the functioning of complex systems, in particular the use of an enemy deterrence system, depends on its composition and is estimated by many indicators. This makes it necessary to use the methods of multi-criteria analysis when justifying the composition of systems (choosing a rational composition). To determine the rational composition of the enemy's deterrence forces, it is advisable to use the taxonomy method.

The study is carried out under the conditions of rebuffing the enemy's air offensive operation. Therefore, the following assumptions are accepted:

– during hostilities, the parties consistently exchange missile and air strikes (MAS);

– in the intervals between MAS, hostilities are not carried out;

– additional forces and means of armed struggle are not involved.

5. Results of the study on determining the composition of the enemy's deterrence forces

5. 1. Determination of the criterion for the effectiveness of deterring the enemy from unleashing armed aggression

The main goal of the air offensive operation, which can be carried out by the enemy at the beginning of armed aggression, is to gain air superiority, which can be achieved by the ratio of the combat potentials of the aviation forces of the opposing sides at the end of the operation $S_{sup}^{av}=1.5-2.0$ [12]. To deter a possible enemy from unleashing armed aggression, it is necessary to have such forces and means of armed struggle that will not allow it to ensure such a balance of combat potentials of the aviation forces of the parties at the end of the operation.

If at the end of the operation the combat capability ratio of the aviation forces of the parties S_{op}^{av} does not change compared to the original one S_0^{av}, it can be assumed that the effectiveness of deterrence is E=1. On the contrary, if at the end of the operation $S_{op}^{av}=S_{sup}^{av}$, the effectiveness of deterrence is E=0. Under such conditions, the effectiveness of deterrence can be determined by the formula:

$$E=1-\frac{S_{op}^{av}-S_0^{av}}{S_{sup}^{av}-S_0^{av}};\quad S_{op}^{av}\geq S_0^{av};\quad S_{sup}^{av}>S_0^{av}. \qquad (1)$$

Thus, it is advisable to consider the effectiveness of deterrence, which is determined by the formula (1), as a criterion.

To meet the requirement for a given deterrence efficiency E_{spec}, it is necessary to ensure the balance of the combat potentials of the aviation forces of the parties at the end of the operation:

$$S_{nec}^{av}=S_{sup}^{av}\left(1-E_{spec}\right)+E_{spec}S_0^{av}. \qquad (2)$$

An additional indicator should be considered the overall ratio of the combat potentials of all forces and means of the parties participating in hostilities S_{ov} at the end of the operation.

5. 2. Decomposition of the deterrence system

In the practice of researching complex military systems, a morphological slice is most often used, which practically determines their structure. The morphological slice corresponds to the division of the system according to the functional basis, that is, in accordance with the tasks performed by the elements of the system. Such tasks of the elements of the deterrence system are to destroy the enemy's means during hostilities. The decomposition of the deterrence system, which was carried out taking into account work [10], is shown in Fig. 1.

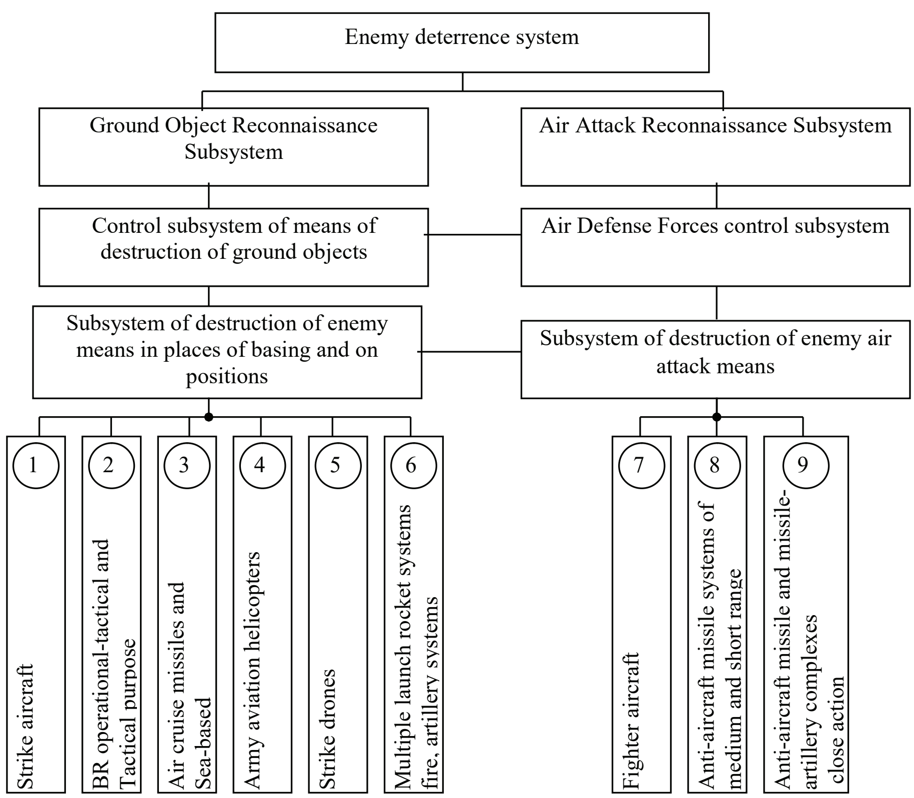

Fig. 1. Decomposition of the enemy's deterrence system

Subsystems of destruction of enemy deterrence systems form n types of means $\left(i=\overline{1,n}\right)$, the numbers of which are shown in Fig. 1. It is believed that the enemy may have the same means, the numbers of which $j=\overline{1,n}$, that is, it forms similar subsystems of destruction of deterrence forces. In this case, military actions to deter the enemy from unleashing armed aggression can be seen as a confrontation between two complex systems of the same structure.

5. 3. General sstructural scheme for the construction of the methodology

The determination of the composition of the deterrence forces is carried out in accordance with the specified effectiveness of deterring the enemy from unleashing armed aggression E_{spec}.

Given the uncertainty of the composition of the means of a possible enemy that can be used in the operation, in accordance with the principles of system analysis, the method of determining the composition of the deterrence forces is based on the assessment of options for the composition of the forces of the opposing parties. The general block diagram of the construction of the methodology is shown in Fig. 2.

The formation of variants of the composition of enemy forces D_r $(r=\overline{1,R})$ is carried out using the heuristic method. To counter the enemy using the experiment planning method [13], variants of the composition of the deterrence forces A_s $(s=\overline{1,C})$ are formed. For this, it is advisable to use ready-made experimental plans. The scheme of combining variants of the composition of the deterrence forces A_s and enemy forces D_r is shown in Fig. 3.

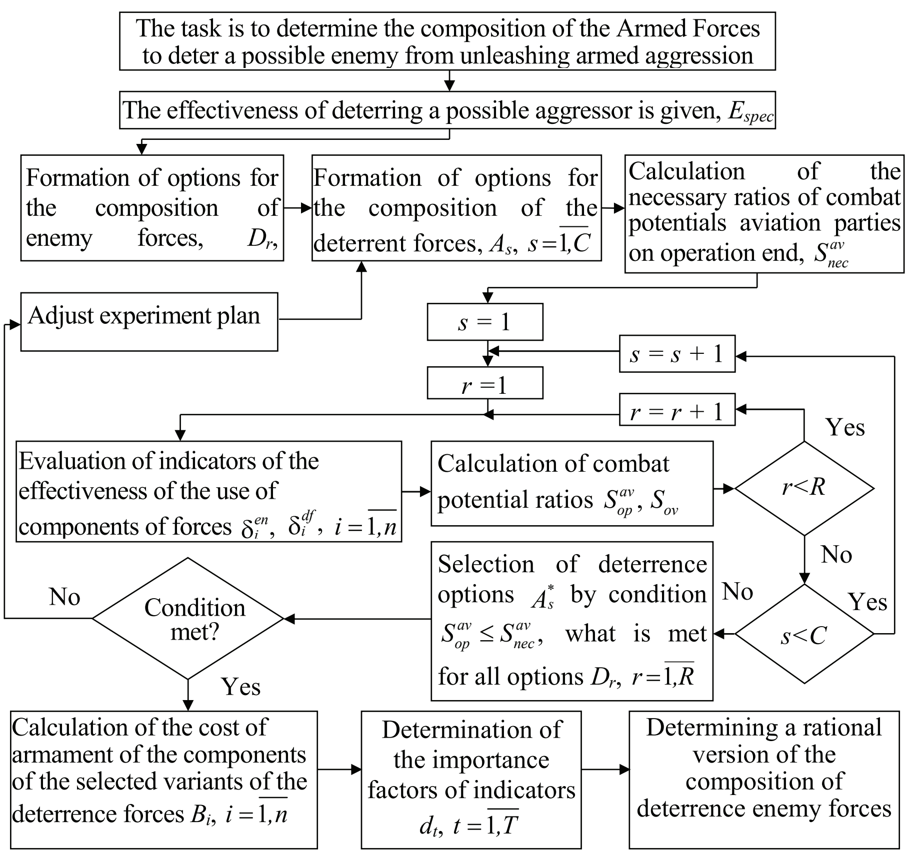

Fig. 2. General block diagram of the methodology construction

The number of options for the composition of the deterrence forces (C) is determined by the experiment plan. When drawing up an experiment plan, the number of units with weapons varies, which is shown in Fig. 1. Some of them may not change when drawing up an experiment plan. The scope of variation in the number of units (parameters) is determined on the basis of the available forces that can be involved in deterring a possible enemy. It is advisable to determine the parameters of the experiment in the combat potentials of the units.

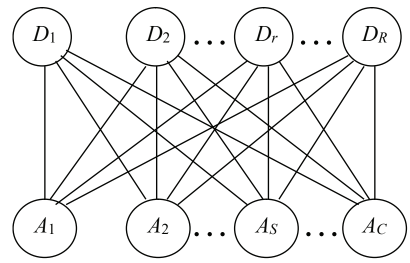

Fig. 3. The scheme of combining options for the composition of deterrence forces and enemy forces

The combat potentials of units of the deterrence forces and enemy forces are calculated using linear dependences:

$$U_i^{df}=m_i^{df}F_i^{df},\ \ U_j^{en}=m_j^{en}F_j^{en},\ \ i=j=\overline{1,n}, \tag{3}$$

where m_i^{df}, m_j^{en} is the number of type I weapons in the deterrence forces unit and of type J in the enemy unit (respectively); F_j^{df}, F_j^{en} – combat potentials of weapons of the i-th type of deterrence forces and the j-th type of enemy (respectively).

The combat potentials of weapons are quantitative indicators of their impact on the results of hostilities, which are average in terms of conditions and tasks performed.

The combat potential of the weapon sample is a value proportional to the average damage that a sample of the opposing group of troops can cause during the fighting [14].

At the beginning of the military conflict, the opposing parties will exchange the MAS, in the rebuffing of which the means of armed struggle will be used, as shown in Fig. 1. The number of exchanges of MAS(K) by the opposing parties is determined by the duration of the projected hostilities.

The combat capabilities of deterrence forces depend on the ratio in their composition of units armed with different types of weapons and are assessed by a set of performance indicators.

In the methodology, the following performance indicators are adopted:

– mathematical expectation of the predicted value of the relative losses of combat potential, which can be inflicted on the enemy by the i-th component of the deterrence forces, δ_i^{en};

– mathematical expectation of the projected value of the relative losses of combat potential of the i-th component of the deterrence forces that can be inflicted by the enemy, δ_i^{df}.

Performance indicators δ_i^{en}, δ_i^{df} are determined for all combinations of options for the composition of deterrence forces and enemy forces (Fig. 3).

According to the indicators δ_i^{en}, δ_i^{df} the ratio of the combat potentials of the aviation forces S_{op}^{av}a nd the total ratio of the combat potentials of the forces of the opposing sides of S_{ov} at the end of hostilities are calculated. Next, the choice is made of options for deterrence forces A_s^*, for which the condition $S_{op}^{av} > S_{nec}^{av}$ is met when opposing any variant of the composition $D_r\left(r=\overline{1,R}\right)$ of the enemy forces, which corresponds to the specified efficiency $E_{spec.}$ Such options A_s^* must be obtained at least as the specified C^*. When the conditions are not met, the experiment plan is adjusted, and the calculations are repeated.

When conditions are met, the cost of the components of the selected deterrence forces B_i, $i=\overline{1,n}$. is calculated.

The set of indicators of efficiency δ_i^{en}, δ_i^{df} and cost B_i taking into account their importance is used when using the taxonomy method to determine the rational version of the composition of the deterrence forces from the selected options.

5. 4. Analytical expressions for determining the relative losses of combat potential and the ratio of forces of the parties

Determination of the projected losses of the enemy when the MAS is inflicted by deterrence forces is carried out using the methodology set forth in work [15].

In the methodology, by iteration, taking into account the available means of defeating the deterrence forces that can take part in MAS, in accordance with the polygon outfits, the number of means of the j-th type of enemy v_{jik} is determined, at which strikes can be struck by the i-th component of the deterrence forces during the k-th exchange of MAS.

The mathematical expectation of the predicted value of the relative losses of combat potential, which can be inflicted on the enemy by the i-th component of the deterrence forces in the k-th MAS, is determined by the formula:

$$\delta_{ik}^{en*} = \frac{\sum_j \nu_{jik} F_j^{en}\left(1-P_{ik}\right)W_{jik}}{\sum_j z_{j0}^{en}U_{j0}^{en}}; \; i=1\text{–}6; j=1, 2, 4\text{–}9, \quad (4)$$

where P_{ik} – probability of destruction of the i-th type of weapon (except for multiple launch rocket systems, i=6) by enemy air defense forces;

z_{j0}^{en}, U_{j0}^{en} – the initial number of units of the j-th type in the composition of the enemy forces and their initial combat potentials, respectively;

W_{jik} – the probability of hitting the j-th type of means by a polygonal outfit of the i-th type of deterrence forces.

In (4), for multiple launch rocket systems, P_{6k}=0.

Similarly, the mathematical expectation of the predicted value of the relative losses of the combat potential of the i-th component of the deterrence forces δ_{ik}^{cc*}, which can be inflicted by the enemy in the k-th MAS, is calculated:

$$\delta_{ik}^{df*} = \frac{\sum_j \mu_{jik} F_j^{df}\left(1-P_{jk}\right)W_{ijk}}{\sum_i z_{i0}^{df}U_{i0}^{df}}; \; i=1, 2, 4\text{–}9; j=1\text{–}6, \quad (5)$$

where μ_{ijk} – the number of means of the i-th type of deterrence forces at which strikes can be carried out by means of the j-th type of enemy in the k-th MAS;

z_{i0}^{df}, U_{i0}^{df} – the initial number of type I units in the composition of the deterrence forces and their initial combat potentials;

P_{jk} – the probability of hitting the j-th type of enemy by means of air defense of the deterrence forces (P_{6k}=0).

The probabilities W_{ijk}, W_{jik} are usually set when determining polygonal outfits of means for hitting objects.

When determining the probabilities P_{ik}, P_{jk} and assessing enemy losses and deterrence forces when rebuffing MAS, the following should be considered:

– strike and fighter aircraft, unmanned aerial vehicles, helicopters can be affected by all air defense systems;

– cruise missiles – by all means of air defense, except for fighter aircraft;

– ballistic missiles – medium and short-range air defense systems;

– projectiles of multiple launch rocket systems are not rebuffed by air defense.

The mathematical expectation of the predicted value of the relative losses of the enemy's combat potential, which can be inflicted by the i-th air defense systems (i=7–9) when rebuffing the k-th MAS, is determined by the formula

$$\delta_{ik}^{en*} = \frac{\sum_j m_{j0}^{en} z_{j0}^{en} F_j^{en} P_{jik}}{\sum_j z_{j0}^{en}U_{j0}^{en}}, \quad (6)$$

where P_{jik} is the probability of hitting the enemy's j-th type of weapon by the i-th means of deterrence forces when rebuffing the k-th MAS.

A general expression for determining the probability of hitting a target from the composition of a strike with anti-aircraft complexes is:

$$P_{hit} = P_{det}P_{fir}\left[1-\left(1-R_1\right)^{\xi}\right], \quad (7)$$

where P_{det} – probability of detection of the target;

P_{fir} – the probability of firing the target;

R_1 – conditional probability of hitting the target with one missile (in one shooting);

ξ – the number of missiles (firing) intended to hit the target.

To determine the probability of firing P_{firjik} at aircraft, helicopters, unmanned aerial vehicles, medium and short-range air defense systems when rebuffing MAS, a model of a mass service system with a limited time spent in the queue is used.

The intensity of the flow of air attack means (AAM) coming in to fire at one unit of the i-th type deterrence forces is determined by the formula (index k omitted)

$$\lambda_{ji} = \frac{\sum_j P_{detj} m_j^{en} z_j^{en}}{t_{st} z_i^{df}}, \; j=1, 4, 5, 7, \quad (8)$$

where t_{st} is the duration of the enemy's MAS.

The average intensity of AAM Y fire and the average intensity of the flow of AAM h leaving the system due to the limited time spent in the system are determined by the formulas:

$$Y = \frac{1}{T_c}; \; h = \frac{4}{\sum_j T_{spj}}, \quad (9)$$

where T_c – average time of the air defense system firing cycle;

T_{spj} – the average time spent by the j-th type of AAM in the zone of launch of the air defense system.

To determine the probability of shelling AAM of these types (j=1, 4, 5, 7) of the air defense system (i=8) P_{firji}, a dependence is used, which is obtained taking into account work [16]:

$$P_{firji} = \frac{\lambda_{ji}}{\alpha_{ji} y}\left(1 - q_{ji}^{m_i} P_{n_i}\right), \quad (10)$$

where $\alpha_{ji} = \frac{\lambda_{ji}}{Y}$ – reduced intensity of the flow of AAM;

$$u = Y + h; \quad \alpha_{ji}^* = \frac{\lambda_{ji}}{u}; \quad q_{ji} = \frac{a_{ji}^*}{n_i};$$

$$n_i - m_i^{df} n_{tci};$$

n_{tci} – the number of target channels of one air defense system;

m_i – number of seats in the queue of the subdivision of the i-th type;

P_{ni} – the probability that all channels of the unit are engaged in shooting.

The probability P_{ni} is determined by the formula:

$$P_{n_i} = \frac{a_{ji}^{*n_i}}{n_i!} P_{0i}, \quad (11)$$

where P_{0i} is the probability that all channels are free.

To determine the probability P_{0i}, expression [24] is used:

$$P_{0i} = \left(\sum_{l=0}^{n_i} \frac{a_j^*}{l!} + \frac{a_j^{*n_i}}{n_i!} q_{ji} \frac{1 - q_{ji}^{m_i - 1}}{1 - q_{ji}} \right)^{-1}, \quad q_{ji} \neq 1. \quad (12)$$

To determine the probability of firing P_{firji} of AAM (j=1, 3–5, 7) by short-range anti-aircraft systems (i=9), as well as ballistic and cruise missiles (j=2, 3) of medium and short-range air defense systems (i=8), a model of a failover queuing system is used. The probability P_{firji} is determined by the Erlang formula [16]:

$$P_{firji} = 1 - \frac{\left(\lambda_{ji} T_c\right) \frac{1}{n_i!}}{\sum_{l=0}^{n_i} \left(\lambda_{ji} T_c\right)^l \frac{1}{l!}}. \quad (13)$$

In determining the probability of firing ballistic and cruise missiles, the intensity of flight of only these AAM is taken into account.

The probability of damage to the AAM by anti-aircraft complexes is determined by the formula:

$$P_{ji} = P_{firjji}\left[1 - \left(1 - R_{1ji}\right)^{\xi}\right]. \quad (14)$$

The probability of destruction of the enemy's AAM(j=1, 4, 5, 7) by one group of fighters of the deterrence forces (i=7) is determined by the following formula [10]:

$$P_{ji} = P_{det} P_{ris} P_{point}\left[1 - \left(1 - R_{1j}\right)^{\xi^*}\right], \quad (15)$$

where P_{ris} – the probability that by the time the target reaches the line of the fighter rise, at least one guidance channel and at least one fighter will be free;

P_{point} – the probability of pointing a fighter (group) at the target;

R_{1j} – the conditional probability of hitting the j-th type target with one fighter;

ξ^* – the number of fighters in the group.

The probability P_{ris} is determined by the Erlang formula, the probability P_{point} is determined by the Laplace distribution function, taking into account the error of guiding the fighter on the course.

Mathematical expectation of the predicted value of the relative losses of the combat potential of the i-th component of the deterrence forces that can be inflicted by the enemy when rebuffing the k-th MAS:

$$\delta_{ik}^{df*} = \frac{m_{ik}^{df} z_{ik}^{df} F_i^{df} P_{ik}}{\sum_i z_{i0}^{df} U_{i0}^{df}}. \quad (16)$$

The probability of hitting the means of the i-th type of deterrence forces by means of enemy air defense P_{ik} and means of the j-th type of enemy forces by means of air defense of the deterrent forces P_{jk} is determined as follows:

$$P_{ik} = \frac{\sum_j P_{ijk} m_{ik} z_{ik}}{\sum_i m_{ik} z_{ik}};$$

$$P_{jk} = \frac{\sum_i P_{jik} m_{jk} z_{jk}}{\sum_j m_{jk} z_{jk}}. \quad (17)$$

The probability of hitting the means of the i-th type of deterrence forces by the enemy's air defense systems P_{ijk} is determined similarly to the determination of the probability P_{jik}.

The mathematical expectations of the projected values of the relative losses of combat potentials inflicted on the enemy by the i-th component of the deterrence forces δ_i^{en} and which are inflicted by the i-th component of the enemy's deterrence forces δ_i^{df} under K exchanges of MAS are determined by the formulas:

$$\delta_i^{en} = \sum_k \delta_{ik}^{en*} + \sum_k \delta_{ik}^{en**},$$

$$\delta_i^{df} = \sum_k \delta_{ik}^{df*} + \sum_k \delta_{ik}^{df**}, \quad k = \overline{1,K}. \quad (18)$$

Initial ratios of the combat potentials of the opposing sides:

$$S_{ov} = S_{ov0} \cdot \frac{1 - \sum_i \delta_i^{en}}{1 - \sum_i \delta_i^{df}}, \quad i = j = \overline{1,n};$$

$$S_0^{av} = \frac{\sum_j z_{j0}^{en} U_{j0}^{en}}{\sum_i z_{i0}^{df} U_{i0}^{df}}, \quad i=j=1,\ 4,\ 7. \quad (19)$$

The ratio of the combat potentials of the opposing sides at the end of the operation:

$$S_{ov} = S_{ov0} \cdot \frac{1 - \sum_i \delta_s^{en}}{1 - \sum_i \delta_s^{df}}, \quad i = \overline{1,n};$$

$$S_{op}^{av} = S_0^{av} \cdot \frac{1-\sum_i \delta_i^{en}}{1-\sum_i \delta_i^{df}}, \ \text{i=1, 4, 7.} \quad (20)$$

The ratio of combat potentials S_{ov}, S_{op}^{av} is calculated for each s-th variant of the composition of deterrence forces that counteract each r-th version of the enemy forces (Fig. 3).

5. 5. Determining the rational composition of deterrence forces

When applying the taxonomy method to determine the composition of deterrence forces, it is necessary to assess the significance (importance) of indicators δ_i^{en}, δ_i^{df}, $B_i(i=\overline{1,n})$. The importance factors of indicators, given their large number, are determined in two stages using the expert method of pairwise comparisons and the nine-point Saaty scale [17]. Expert assessment of the importance of indicators is carried out by specialists with experience in operations (hostilities).

At the first stage, the importance of groups of indicators δ_i^{en}, δ_i^{df}, B_i is assessed. In the second stage – indicators inside these groups. Experts should make matrices of pairwise comparisons (Table 1), the elements of which are the ratio of weights of groups of indicators or indicators within the groups ω_i/ω_j $\left(i=j=\overline{1,n}\right)$.

Table 1

Matrix of pairwise comparisons for a group of indicators $\delta_i^{en}\left(i=\overline{1,n}\right)$

Indicator	δ_1^{en}	δ_2^{en}	...	δ_j^{en}	...	δ_n^{en}
δ_1^{en}	1	ω_1/ω_2	...	ω_1/ω_j	...	ω_1/ω_n
δ_2^{en}	ω_2/ω_1	1	...	ω_2/ω_j	...	ω_2/ω_n
⋮	⋮	⋮	⋮	⋮	⋮	⋮
δ_i^{en}	ω_i/ω_1	ω_i/ω_2	...	1	...	ω_i/ω_n
⋮	⋮	⋮	⋮	⋮	⋮	⋮
δ_n^{en}	ω_n/ω_1	ω_n/ω_2	...	ω_n/ω_j	...	1

The strings of the matrix are used to calculate the components of its eigenvector:

$$a_i = \sqrt[n]{\frac{\omega_i}{\omega_1}\times\frac{\omega_i}{\omega_2}\times\ldots\times\frac{\omega_i}{\omega_j}\times\ldots\times\frac{\omega_i}{\omega_n}} = \sqrt[n]{\prod_j \frac{\omega_i}{\omega_j}}, \quad i=j=\overline{1,n}. \quad (21)$$

The priority of the i-th indicator δ_i^{en} is determined by the formula:

$$b_i^{en} = \frac{a_i}{\sum a_i}; \quad i=\overline{1,n}, \quad \sum_i b_i^{en} = 1. \quad (22)$$

The judgment of experts is checked for consistency. To do this, we apply the ratio of consistency, which is calculated using the obtained priorities of indicators [17].

Similarly, the importance coefficients b_i^{en}, b_i^{B} of indicators within the groups δ_i^{df}, B_i are determined, as well as the importance coefficients of groups C_{en}, C_{df}, C_B. Finally, the coefficients of importance of indicators are calculated as follows:

$$d_i^{en} = C_{en} b_i^{en}; \quad d_i^{df} = C_{df} b_i^{df}; \quad d_i^{B} = C_B b_i^{B};$$

$$\sum_i d_i^{en} + \sum_i d_i^{df} + \sum_i d_i^{B} = 1, \quad i=\overline{1,n}. \quad (23)$$

To use the taxonomy method, all indicators are numbered in order and receive the designation $x_t(t=\overline{1,T})$ Indicators δ_i^{en} correspond to: t=1–9; indicators $\delta_i^{df}-t=10÷18$; indicators B_i–t=19–27.

Using the taxonomy method, selected variants A_S^* of the composition of deterrence forces are compared. In accordance with the procedure for applying the taxonomy method [18], a matrix of average values of indicators $\|x_{ts}\|$, $t=\overline{1,T}$, $s=\overline{1,C^*}$. is compiled. Further, the indicators are reduced to a standardized form according to the formula:

$$z_{ts} = \frac{x_{ts} - \overline{x_t}}{\sigma_t}, \quad (24)$$

where $\overline{x_t} = \frac{1}{C^*}\sum_s x_{ts}$; $\sigma_t = \sqrt{\frac{1}{C^*}\sum_s \left(x_{ts} - \overline{x_t}\right)^2}$.

Thus, the matrix $\|x_{ts}\|$ is transformed into an equivalent (standard) matrix $\|z_{ts}\|$.

To determine the rational version of the composition of the deterrence forces, the concept of an ideal or reference composition is introduced. For this, the indicators are divided into stimulants F and destimulants Q. Stimulants include indicators δ_i^{en}, destimulants – δ_i^{df}, B_i.

The reference version of the composition of the deterrence forces corresponds to the values of standardized indicators:

$$z_{10},\ z_{20},\ \ldots,\ z_{t0},\ z_{T0}, \quad (25)$$

where $z_{t0} = \max_s z_{ts}$, when $t \in F$; $z_{t0} = \min_s z_{ts}$, when $t \in Q$.

The distances between the indicators of the reference version of the composition and others are determined by the following formula [18]:

$$\gamma_{0s} = \left[\sum_t d_t^2 \left(z_{ts} - z_{t0}\right)^2\right]^{\frac{1}{2}}, \quad t=\overline{1,T}, \quad s=\overline{1,C^*}, \quad (26)$$

where d_t is the importance factor of the t-th indicator.

The degree of superiority of the options for the composition of deterrence forces is determined by the formula:

$$\beta_S = 1 - \frac{\gamma_{0S}}{\gamma_0}, \quad (27)$$

where $\gamma_0 = \overline{\gamma_0} + 2\sigma_0$; $\overline{\gamma_0} = \frac{1}{C^*}\sum_{s=1}^{C^*}\gamma_{0s}$; $\sigma_0 = \left[\frac{1}{C^*}\sum_{s=1}^{C^*}\left(\gamma_{0s} - \overline{\gamma_0}\right)^2\right]^{\frac{1}{2}}$.

The rational option is the composition of the deterrence forces for which the indicator β_s is maximum.

The rational version of the composition of the deterrence forces corresponds to the determined combat potentials of the units, and therefore the quantitative composition of the means of destruction to deter the enemy. Thus, in accordance with the systematic approach, the composition of the enemy's deterrence system was carried out – combining the required number of weapons into the system.

The procedure of determining the composition of the enemy's deterrence forces is based on the use of experiment planning methods, queuing theory, iterations, pairwise comparisons, and taxonomy. The use of these methods and the consistent conduct of calculations in accordance with the exchange of MAS between the opposing parties makes it possible to take into account the complex nature of the use of heterogeneous means of destruction in order to deter a possible enemy from unleashing armed aggression.

The use of the devised methodology is shown on the example of determining the composition of the enemy's deterrence forces.

Two variants of the composition of enemy forces and ten options for the composition of the deterrence forces are considered. It is accepted that strike aircraft, helicopters, fighter aircraft, medium and short-range air defense systems, and close-range anti-aircraft systems take part in hostilities on both sides. When drawing up a plan of experiments, the initial combat potentials of strike aviation, fighter aircraft, medium and short-range air defense systems varied.

The assigned effectiveness of deterring the enemy E_{spec}=0.7. The ratio of the combat potentials of the aviation sides to gain air superiority is $S_{sup}^{av}=1.75$.

The initial combat potentials and the results of calculating the ratios of the forces of the opposing sides are given in Table 2.

From the analysis of Table 2 it follows that the condition $S_{op}^{av} \leq S_{nec}^{av}$ is met for 4, 6, 8, 9, 10 variants of the composition of the deterrence forces, from which it is necessary to choose a rational one using the taxonomy method. Table 3 gives the indicators and coefficients of their importance for determining the rational version of the composition of the deterrence forces.

The cost of arming the components of the deterrence forces was determined relative to the unit corresponding to the maximum combat potential of strike aircraft according to the options.

The results of the calculation of the taxonomic indicator β_s (the corresponding software is used) are shown in Fig. 4.

From the analysis of the results obtained, it turns out that the dominant influence on determining the composition of the deterrence forces is exerted by the combat potentials of strike aircraft and medium-range and medium-range air defense systems, which have the greatest effectiveness of defeating the enemy and the maximum cost of funds. For the initial data adopted in the example, the fourth version of the composition of the deterrence forces is rational, which corresponds to the maximum combat potential of strike aircraft, the minimum combat potential of fighter aircraft and the average combat potential of the air defense system. The worst is the ninth option, which corresponds to the maximum combat potentials of the components of the deterrence forces, which is caused by the impact of the cost of their means.

Table 2

Initial combat potentials and the balance of forces

Initial combat potentials of the means of defeating the opposing sides	Variants of enemy forces, r		Deterrence composition options, S									
	1	2	1	2	3	4	5	6	7	8	9	10
Strike aircraft	2500	3000	1800	1800	1800	2600	1800	2200	1800	2600	2600	2200
Helicopters	500	600	400	400	400	400	400	400	400	400	400	400
Fighter aircraft	1000	600	800	800	600	400	400	600	400	600	800	800
Medium and short-range air defense systems	300	400	250	350	300	300	250	350	350	250	350	300
Close action ZK	100	200	150	150	150	150	150	150	150	150	150	150
The ratio of combat potentials for the first version of the enemy forces	S_{ov0}		1.29	1.26	1.35	1.14	1.47	1.19	1.42	1.10	1.02	1.14
	S_0^{av}		1.33	1.33	1.43	1.18	1.54	1.25	1.54	1.11	1.05	1.18
	S_{nec}^{av}		1.45	1.45	1.53	1.35	1.60	1.40	1.60	1.30	1.26	1.35
The ratio of combat potentials for the second version of the enemy forces	S_{ov0}		1.41	1.37	1.28	1.25	1.60	1.30	1.55	1.20	1.12	1.25
	S_0^{av}		1.40	1.40	1.50	1.23	1.61	1.31	1.61	1.17	1.10	1.23
	S_{nec}^{av}		1.50	1.50	1.57	1.39	1.65	1.44	1.65	1.34	1.29	1.38
The ratio of combat potentials at the end of the operation for the first version of the enemy forces	S_{ov}		1.61	1.38	1.43	1.22	1.83	1.22	1.52	1.24	1.10	1.26
	S_{op}^{av}		1.65	1.45	1.59	1.27	1.89	1.30	1.63	1.25	1.13	1.33
The ratio of combat potentials at the end of the operation for the second version of the enemy forces	S_{ov}		1.96	1.62	1.49	1.48	2.07	1.42	1.82	1.43	1.30	1.49
	S_{op}^{av}		2.23	1.65	1.74	1.36	2.08	1.40	1.87	1.34	1.28	1.35

Table 3

Indicators and coefficients of their importance

Deterrence composition option (number)	Average relative losses of combat potential that can be inflicted on the enemy by components of the deterrence forces, x_t, t=1–5, %					Average relative losses of combat potential that can be inflicted by the enemy on the components of the deterrence forces, x_t, t=6–10, %					The cost of weapons of the components of the deterrence force, x_t, t=11–15, conditional units				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	15.0	3.0	3.0	5.0	3.0	15.5	4.0	4.0	7.5	4.0	1.0	0.12	0.15	0.35	0.11
6	13.5	3.0	4.0	6.5	3.0	15.0	4.0	4.0	7.0	4.0	0.83	0.12	0.23	0.40	0.11
8	14.0	3.0	3.5	4.0	3.0	17.5	4.0	5.5	6.5	4.0	1.00	0.12	0.23	0.25	0.11
9	14.5	2.5	3.0	5.5	3.5	16.0	4.0	5.0	7.5	4.0	1.00	0.12	0.30	0.40	0.11
10	13.5	3.0	3.5	6.0	3.0	16.0	4.0	4.0	7.5	4.0	0.83	0.12	0.30	0.35	0.11
Importance factor d_t	0.21	0.03	0.07	0.14	0.05	0.12	0.03	0.04	0.07	0.04	0.08	0.02	0.03	0.05	0.02

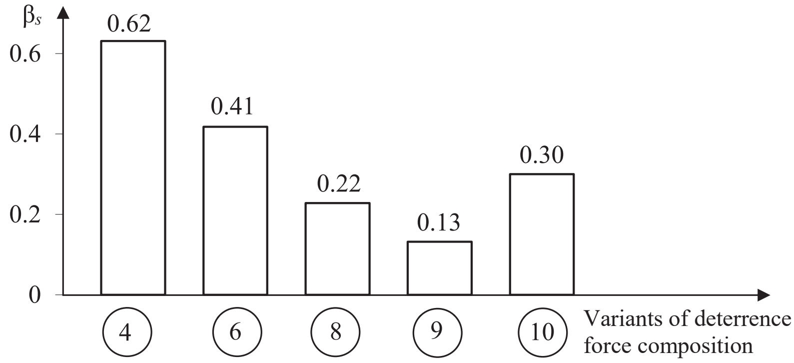

Fig. 4. The results of the calculation of the taxonomic indicator

The limitation of the use of the developed procedure is to take into account the available or prospective number of means of defeating the Armed Forces in the formation of options for the composition of the enemy's deterrence forces (Table 2).

The methodology makes it possible to take into account the complex nature of the use of heterogeneous means of armed struggle in justifying the necessary combat composition of forces to solve the problem of deterring the enemy from solving armed aggression. The procedure can be used under the condition that the enemy conducts an air offensive operation during which MAS are exchanged between the opposing parties.

The disadvantage of the study is the consideration in the methodology of general means of destruction (Fig. 1). In the future, it is possible to divide them into types, which will make it possible to obtain more accurate results. However, this will complicate mathematical dependences to assess the effectiveness of the use of enemy deterrence forces.

6. Discussion of results of the study on determining the composition of the enemy's deterrence forces from unleashing armed aggression

The study is aimed at further development of methodological provisions for substantiating the necessary combat composition of forces to perform the assigned tasks by the group of troops, in particular in order to deter the enemy from unleashing armed aggression.

Based on the application of the systematic approach, more advanced analytical dependences (4) to (6), (16) have been developed to assess the loss of combat capabilities of the opposing sides during hostilities. Our dependences will allow the most reasonable consideration of the influence of the quantitative composition of heterogeneous means of destruction on the task of deterring the enemy from unleashing armed aggression.

In contrast to existing approaches [13, 14], the composition of the deterrence forces is determined taking into account the fulfillment of a given criterion of deterrence effectiveness, the dependence (1) for the calculation of which was obtained during the study. According to the criterion, taking into account the initial and accepted balance of forces of the aviation of the parties to gain air superiority, the required balance of aviation forces at the end of hostilities is determined in order to prevent the enemy from performing the task (2).

Given the uncertainty of the enemy's forces, when determining the composition of the deterrence forces from the resolution of armed aggression, a variant method is used. The choice of the rational composition of the deterrence forces is carried out using the taxonomy method. At the same time, the importance of indicators of the effectiveness of the use of opposing parties and the cost of deterrence is assessed by the method of pairwise comparisons (Table 1). The peculiarity of the application in the method of taxonomy is to take into account only the options for the composition of the deterrence forces, for which the condition is not exceeding the required ratio of the combat potentials of the aviation forces of the parties at the end of hostilities is fulfilled (Fig. 2). This approach makes it possible to more reasonably determine the composition of the deterrence forces from the resolution of armed aggression.

As shown by our example, the methodology makes it possible to assess the impact of the combat potentials of the constituent forces on the effectiveness of deterrence, which is important when planning their use.

7. Conclusions

1. During the study, the criterion of the effectiveness of deterring the enemy from unleashing armed aggression is substantiated, which is determined by the required ratio of combat potentials of the aviation of the opposing sides at the end of hostilities.

2. The totality of the forces and means of the opposing parties are considered as complex systems. To determine the indicators of the effectiveness of the use of elements of the enemy's deterrence system, its decomposition was carried out on the means participating in hostilities.

3. A block diagram of the methodology for determining the composition of the enemy's deterrence forces has been developed, which is based on assessing the effectiveness of the components of the deterrence forces according to the options and determining the rational option from them, taking into account the cost.

4. Analytical dependences were derived to assess the effectiveness of the task and the rebuffing of MAS by the opposing parties, taking into account the use of heterogeneous means of armed struggle. This made it possible to more objectively assess the ratio of the combat potentials of the parties at the end of hostilities.

5. To solve the multicriterial problem of comparing the variants of the composition of the enemy's deterrence forces the taxonomy method was used. This has made it possible to determine the rational (balanced) composition of the enemy's deterrence forces in terms of the effectiveness of the use of components of the deterrence forces and the cost of their weapons.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

References

1. Bonin, A. S. (2014). Metodika obosnovaniya neobkhodimogo sostava aviatsionnoy gruppirovki na strategicheskom napravlenii v operatsiyakh nachal'nogo perioda voyny. Vestnik Akademii voennykh nauk, 3 (48), 39–42.
2. Laneckij, B. N., Lukyanchuk, V. V., Vasilyev, V. A., Koval, I. V. (2012). Development of research on methodological preliminary rationale required quantitative and qualitative composition of the anti-aircraft missile armed group antiaircraft missile troops. Nauka i tekhnika Povitrianykh Syl Zbroinykh Syl Ukrainy, 3, 58–60. Available at: http://nbuv.gov.ua/UJRN/Nitps_2012_3_15
3. Zahorka, O., Zahorka, I., Polishchuk, S. (2020). Justification of the Optimal Composition of the Air Defense Troops Grouping. Advances in Military Technology, 15 (1), 55–65. doi: https://doi.org/10.3849/aimt.01303
4. Ryan, A. J. (2011). Military Applications of Complex Systems. Philosophy of Complex Systems, 723–780. doi: https://doi.org/10.1016/b978-0-444-52076-0.50024-9
5. Butvin, B. L., Kryvosheev, V. M. (2008). Ratsionalnyi vybir variantu skladnoi tekhnichnoi systemy u bahatokryterialniy postanovtsi zadachi. Suchasni informatsiyni tekhnolohiyi u sferi bezpeky ta oborony, 3 (3), 10–16.
6. Ostankov, V. I., Kazari, P. S. (2012). Metodika sravnitel'noy otsenki boevykh potentsialov voyskovykh formirovaniy i kachestvennogo sootnosheniya sil storon v operatsiyakh. Voennaya mysl', 11, 47–57.
7. Brauers, W. K., Zavadskas, E. K. (2009). Robustness of the multi-objective moora method with a test for the facilities sector. Technological and Economic Development of Economy, 15 (2), 325–375. doi: https://doi.org/10.3846/1392-8619.2009.15.352-375
8. Baležentis, A., Baležentis, T., Brauers, W. K. M. (2012). MULTIMOORA-FG: A Multi-Objective Decision Making Method for Linguistic Reasoning with an Application to Personnel Selection. Informatica, 23 (2), 173–190. doi: https://doi.org/10.15388/informatica.2012.355
9. Kundakcı, N. (2018). An integrated method using MACBETH and EDAS methods for evaluating steam boiler alternatives. Journal of Multi-Criteria Decision Analysis, 26 (1-2), 27–34. doi: https://doi.org/10.1002/mcda.1656
10. Zahorka, O., Shchipanskyi, P., Pavlikovskyi, A., Oksiiuk, O., Vialkova, V. (2019). Development of methodical provisions regarding the substantiation of the combat structure of forces for activities in the airspace. Eastern-European Journal of Enterprise Technologies, 2 (3 (98)), 6–15. doi: https://doi.org/10.15587/1729-4061.2019.163082
11. Zahorka, A., Polishuk, S. (2021). Substantiation of the combat composition of the enemy's deterrent forces in crisis situations: methodological provisions. Zbirnyk Naukovykh Prats Tsentru Voienno-Stratehichnykh Doslidzhen NUOU Imeni Ivana Cherniakhovskoho, 3 (73), 22–32. doi: https://doi.org/10.33099/2304-2745/2021-3-73/22-32
12. Rudenko, A. V. (1998). O kriteriyakh dostizheniya tseley vozdushnykh operatsiy i operatsiy obedineniy VVS. Voennaya mysl', 2, 46–52.
13. Barabaschuk, V. I., Kredentser, B. P., Miroshnichenko, V. I.; Kredentser, B. P. (Ed.) (1984). Planirovanie eksperimenta v tekhnike. Kyiv: Tekhnika, 200.
14. Tomashev, V. N. (2006). O sovershenstvovanii metodov otsenki boevykh vozmozhnostey voysk. Nauka i voennaya bezopasnost', 2, 18–22.
15. Zahorka, O. M., Pavlikovskyi, A. K., Koretskyi, A. A., Kyrychenko, S. O., Zahorka, I. O. (2020). Teoretychni osnovy upravlinnia uhrupovanniam viysk (syl) u suchasnykh umovakh zbroinoi borotby. Kyiv: NUOU im. Ivana Cherniakhovskoho, 248.
16. Shuenkin, V. A., Donchenko, V. S. (1992). Prikladnye modeli teorii massovogo obsluzhivaniya. Kyiv: NMK VO, 398.
17. Saati, T., Kerns, K. (1991). Analiticheskoe planirovanie: organizatsiya sistem. Moscow: Radio i svyaz', 224.
18. Plyuta, V. (1989). Sravnitel'niy mnogomernyy analiz v ekonometricheskom modelirovanii. Moscow: Finansy i statistika, 176.