Methodology for substantiating the choice of the optimal aerial and ground reconnaissance-strike complexes according to the integral criterion “efficiency-cost-time”

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Abstract: *In the modern realities of the development of the Armed Forces of Ukraine, the current issue is the search for ways to create new aerial and ground integrated reconnaissance-strike complexes that are capable of quick reconnaissance and attack of an enemy. However, a reasonable choice of such a system should not create an excessive burden for the state economy in terms of its development, maintenance, and application, and must also have the prospect of timely bringing it to combat readiness. Therefore, this study considers a methodology for substantiating the choice of an optimal option of the reconnaissance-strike complex or system for its use in operations when developing programmes and development plans of the AF of Ukraine. The proposed methodology has an integral criterion for choosing a rational option of a reconnaissance-strike complex, which combines indicators for assessing the efficiency of the combat use of these systems under various conditions, the sufficiency of the state economic capabilities for its creation, maintenance, and use, and assessing the timeliness of its creation and bringing it to combat readiness. The method is based on a mathematical model of* *game theory. The decision to choose a particular option of the reconnaissance-strike complex occurs in conditions of uncertainty of the combat situation and the volume of tasks that would rely on these systems when performing combat tasks.*

Key Words: *aerial, combat efficiency, the sufficiency of economic capabilities of the state, timely creation and bringing to combat readiness, matrix mathematical model.*

1. INTRODUCTION

One of the significant indicators that affect the level of defence sufficiency of the state is the quantitative and qualitative state of weapons and military equipment (WME) of the armed forces (AF). A priority goal of any leadership of the armed forces and the state as a whole is to have the latest and effective models of military equipment, but creating own or purchasing foreign models of military equipment is one of the most expensive areas of development of the armed forces. The basis of any modern defence structure is its ability to define and achieve the required goals, as well as effectively perform the tasks set. Such defence structures should be effective, that is, able to provide a positive result. At the same time, they should be able to achieve the required result in conditions of minimising the cost of defence resources, or maximising the expected result of their operation in conditions of fixed amounts of defence resources. The development of new solutions for the structural combination of different types of weapons and military equipment samples according to a single plan in order to effectively perform the assigned combat tasks should also have a clear military and economic justification for the feasibility of its practical implementation. One of the most important ways to improve the efficiency of the use of the Armed Forces of Ukraine in operations today is the approach to combining intelligence, control and weapons into a single system in order to increase the efficiency and efficiency of engaging enemy targets during offensive or defensive actions. Therefore, the search for ways to create new or improve and update existing reconnaissance-strike complexes (RSC), taking into account the economic capabilities of the state, is one of the most important problems faced by the leadership of the Armed Forces of Ukraine in the process of their further development.

There are different approaches to the creation of reconnaissance-strike complexes, which differ both in the amount of initial data required and in the volume of calculation [1]. Their use is associated with significant difficulties, which are conditioned by the search for the necessary source data. Due to the fact that combat planning (development of weapon systems) is accompanied by high uncertainty of initial data, in fact, expert decision-making methods are most often used in existing approaches. For example, probabilistic methods require knowledge of the laws of distribution of random variables and their parameters, which can be reliably obtained from the results of experiments (i.e., previous wars) or by modelling, which in turn is complicated by creating a predictable model of combat operations. Full-scale modelling has a very significant cost and cannot predict all the features of the use of enemy troops.

2. MATERIALS AND METHODS

Today, in many countries of the world, the theory of construction and practice of using both new complexes and existing weapons is being revised, taking into account the organisation and conduct of combat operations in a single information space [2]. The question of how to achieve a reduction in the time of the full cycle of combat use of a weapon complex to get ahead of the enemy in achieving the goal is being solved [3]. At the same time, as noted in [4], the state of the national economy and the level of implementation of modern technologies at defence industry enterprises hinder the implementation of all plans for the rearmament of the Armed Forces of Ukraine within the established time frame. The most acceptable approach, both from a military and economic standpoint, is the situational unification of existing forces and means into target systems in a single information space by integrating existing models of military equipment with those that are created taking into account the forces and means of communication and control systems, geoinformation, and other systems. The combination of forces and means into a single reconnaissance-strike complex provides for the creation of several variants (sets) of existing and promising forces and means, the assessment of which will be characterised by indicators of the efficiency of their use, taking into account resource and time restrictions on their creation and bringing to combat readiness. Therefore, today it is necessary to determine the general approach to choosing a rational option of the reconnaissance and strike complex for the armed forces of Ukraine from the set proposed based on the assessments of the efficiency of their combat use and taking into account assessments of the impact of economic, time, and other factors.

The need to reduce the time and improve the quality of performing reconnaissance tasks and further engagement of enemy determines the need to create new reconnaissance-strike complexes (RSC), which implies a certain number of weapons and military equipment, combined into a single system (complex) in the areas of intelligence, control, engagement in order to perform a certain combat task. In the conditions of limited financial resources and restrictions on the ability of the military-industrial complex (MIC) of Ukraine to a full cycle of development of complex WME models (ships, aircraft, etc.) it is advisable to create new RSCs by step-by-step (iterative, evolutionary) [4] implementation of the following stages: analysis of threats and determination of the main tasks of the Armed Forces of Ukraine in the case of probable armed confrontation and development of a multi-level list of critical enemy facilities that are planned to be destroyed; determination of the rational composition of forces and means of RSC for various types of armed confrontations that are able to adequately perform tasks to counter the enemy in the relevant operational areas and promptly engage enemy; development and improvement of forms and methods of conducting combat operations as a part of the JF; improvement of technologies of fire (functional, electronic) damage and support of combat operations; optimisation of the composition of forces and means of RSC, as well as restructuring of combat training programmes, etc. [5].

3. RESULTS AND DISCUSSIONS

A complete structural and logical scheme of the methodology for choosing a rational option of the reconnaissance-strike complex in the operations of the Armed Forces of Ukraine was developed. The methodology consists of five interrelated subparagraphs. Each of them involves the use of separate mathematical methods or their combinations for each method of a single subparagraph of the methodology.

To begin, a database of output data and a group of competent experts for evaluating RSC options are formed. The first subparagraph consists of four main methods for calculations. In the beginning, the number of RSC options of the Armed Forces of Ukraine is first determined $N_i^t = f(n_{scenario}^i)$ according to the number of possible application scenarios (operations) $n_{scenario}^i$ JF or AF of Ukraine as a whole for the t-th year of their development, then based on the results obtained, variants of the composition of possible RSC of the Armed Forces of Ukraine are formed, depending on possible scenarios for the use by the JF or AF of Ukraine as a whole in operations for the t-th year of their development. Possible variants of RSCs of the Armed Forces of Ukraine for solving combat tasks at the JFO level are given in Table 1. Then, the basis of the proposed method for forming groups of competent experts to conduct procedures for evaluating and comparing different variants of RSCs according to the criterion "efficiency-cost-time" was formed [6].

The first step in the selection of a group of competent experts is the development of verbal and numerical scales for comparative assessment of the priority of options for the t-th year, which would allow the group of assembled experts to conduct a pairwise comparison of the priority of hand RSC options without taking into account the specific combat situation to form a coordinated expert opinion. With the help of formed verbal and numerical assessment scales, the problem of forming groups of competent experts is solved $l = \overline{1, L}$ for conducting procedures for evaluating and comparing different RSC options.

Creation of possible RSC options of the AF of Ukraine depending on possible scenarios of application of the AF of Ukraine in operations for the t-th year of their development. Determination of the number of RSC options of the AF of Ukraine according to the determined number of options $N_i^t = f\,(n_{scenario}^t)$ in accordance with the number of possible scenarios (operations) for the application of $n\,_{scenario}^{t}$ for the *t*-th year of their development. Clarification of the composition of the RSC options of the AF of Ukraine of a certain number of options n_i^t in accordance with the scenarios (operations) of application for the *t*-th year of their development (Table 1).

Table 1 – Clarification of the composition of the RSC options of the Armed Forces of Ukraine

RSC option No.	Possible composition of the RSCs of the AF of Ukraine		
	Means of reconnaissance (k =1)	Means of control (k = 2)	Means of attack (k = 3)
1	$Y_m^{1\,k=1}, m \in [1, M]$ – number of means of reconnaissance of the m-th type for the first RSC option	$X_q^{1\,k=2}, q \in [1, Q]$ – number of controls of the q-th type for the first RSC option	$Z_r^{1\,k=3}, r \in [1, R]$ – number of reconnaissance means of the r-th type for the first RSC option
2			
…			
6	$Y_m^{N\,k=1}, m \in [1, M]$ – number of means of reconnaissance of the m-th type for the first RSC option	$X_q^{N\,k=2}, q \in [1, Q]$ – number of controls of the q-th type for the first RSC option	$Z_r^{N\,k=3}, r \in [1, R]$ – number of reconnaissance means of the *r*-th type for the first RSC option

For farther development creation of groups of competent experts $l = \overline{1, L}$ most be made to conduct procedures for evaluation and comparison of different RSC options. Generation of a comparative matrix of RSC options by each *l*-th expert:

$$\|Z_L\| = \left\| \begin{matrix} & x_1 & \dots & x_{1j} \\ x_1 & 1 & a_{12} & a_{2j} \\ \dots & \dots & 1 & \dots \\ x_{ij} & 1/a_{il} & 1/a\,_{ij} & 1 \end{matrix} \right\| a_{ij} = f(x_1, x_2) \quad (1)$$

– comparative assessments (determined by experts).

After this, estimation of reliability of the obtained results of coefficients of a comparative estimation a_{ij} of the matrix |X| for $l = \overline{1, L}$ experts proceed:

$$\bar{a}_{ij} = {}^{1}/_{\mathrm{L}} \cdot \sum_{l=1}^{\mathrm{L}} a_{ij}^{l}\,; S_{ij} = {}^{1}/_{\mathrm{L}-1} \cdot \sum_{l=1}^{L} (a_{ij}^{l} - \bar{a}_{ij})^{2} \tag{2}$$

$V_n = \frac{|\bar{a}_{ij} - a_{ij}|}{S}$ if $\mathbf{V}_n \rangle \mathbf{V}_{preset}$, the result of the assessment of this expert is not considered.

So, if $V_n \rangle V_{preset}$ for $n \geq n/2$ is true, then the l-th expert is a member of the group of competent experts $l \in [1; L]$, and if false, then l-th expert is not included in the group of competent experts $l \in [1; L]$ - their assessment is not taken into account when assessing the efficiency of combat missions by RSC options. With this data, reformation of the comparative matrix of RSC options by each l-th expert could be made.

$$\|A_L\| = \left\| \begin{matrix} & x_1 & \dots & x_{1j} \\ x_1 & 1 & a_{12} & a_{2j} \\ \dots & \dots & 1 & \dots \\ x_{ij} & 1/a_{i1} & 1/a_{ij} & 1 \end{matrix} \right\| \tag{3}$$

Along with preliminary calculation of priority coefficients of RSC options for the t-th year without reference to the combat situation

$$A_j^l = \sqrt[I]{\prod_{j=1}^{J} a_{ij}^l}\,, (j = \overline{1,J}) \Rightarrow A_j^l / \sum_{j=1}^{1} A_j^l \Rightarrow A_j = \frac{1}{L} \cdot \sum_{l=1}^{L} \tag{4}$$

where A_j^l – priority coefficients of the j-th RSC option in relation to the i-th option.

Expert evaluation of possible RSC options of the AF of Ukraine (Nj) for different volumes of combat missions (Vi) by components (reconnaissance, control, attack) must be made, with final selection of the composition of the RSC options of the AF of Ukraine of a certain number of options N_i^t (according to the scenarios (operations) of application for the t-th year of their development of the AF of Ukraine. Let`s generate an evaluation matrix by each l-th expert on efficiency of reconnaissance of j-th RSC option for different volumes of combat task:

$$\|P^{k=1}\| = \left\| \begin{matrix} & N_1 & \dots & N_j \\ V_1 & P_{11}^1 & P_{12}^1 & P_{1j}^1 \\ \dots & P_{i1}^1 & P_{i2}^1 & \dots \\ V_j & P_{i1}^1 & P_{i2}^1 & P_{ij}^1 \end{matrix} \right\| \tag{5}$$

where P_{ij}^{1} – the probability of reconnaissance of a given number of enemy objects.

Then generate an evaluation matrix by each l-th expert on control efficiency of the j-th RSC option for different volumes of combat task:

$$\|P^{k=2}\| = \left\| \begin{matrix} & N_1 & \dots & N_j \\ V_1 & P_{11}^2 & P_{12}^2 & P_{1j}^2 \\ \dots & P_{i1}^2 & P_{i2}^2 & \dots \\ V_j & P_{i1}^2 & P_{i2}^2 & P_{ij}^2 \end{matrix} \right\| \tag{6}$$

where P_{ij}^{2} – the probability of effective control of the i-th RSC option.

And build an evaluation matrix by each *l*-th expert on attack efficiency of the *j*-th RSC option at different volumes of combat task (P_{ij}^3 – the probability of hitting enemy objects (70-80%))

$$\left\| P^{k=3} \right\| = \left\| \begin{matrix} & N_1 & \dots & N_j \\ V_1 & P_{11}^3 & P_{12}^3 & P_{1j}^3 \\ \dots & P_{i1}^3 & P_{i2}^3 & \dots \\ V_j & P_{i1}^3 & P_{i2}^3 & P_{ij}^3 \end{matrix} \right\| \tag{7}$$

General assessment of the efficiency of the *i*-th combat mission by a certain composition of the RSC (probability of CM) could be made with (Equation 8):

$$P_{ij}^{MC} = P_{ij}^1 \cdot P_{ij}^2 \cdot P_{ij}^3 \tag{8}$$

With all above data, creation of a mathematical model for substantiating the choice of a rational RSC option of the AF of Ukraine could be finally done. Let's generate the payment matrix of states $\|W_{ij}^{t}\|$ the efficiency of the combat mission according to the possible strategies of the enemy (A) and possible RSC options (B):

$$\left\| W_{ij}^t \right\| = \left\| \begin{matrix} A/B & B_1 & B_2 & \dots & B_j \\ A_1 & P_{11}^{MC} & P_{12}^{MC} & \dots & P_{i1j}^{MC} \\ A_2 & P_{21}^{MC} & P_{22}^{MC} & \dots & P_{2j}^{MC} \\ A_3 & P_{31}^{MC} & P_{32}^{MC} & \dots & P_{3j}^{MC} \\ \dots & \dots & \dots & P_{ij}^{MC} & \dots \\ A_i & P_{i1}^{MC} & P_{i2j}^{MC} & \dots & P_{ij}^{MC} \end{matrix} \right\| \tag{9}$$

where P_{ij}^{MC} are the payment matrix elements.

Now, preliminary assessment of the feasibility of choosing the RSC option by the criterion of combat efficiency W_{ij}^t could be done. Assessment of the competence of experts is a necessary procedure for solving the problem of choosing RSC option, which would allow forming groups of experts whose consistency of opinion would reduce the error in calculations and increase the reliability of the results obtained regarding the choice of an adequate RSC option. Assessment of the impact of the economic criterion on the choice of a rational option of the RSC of the AF of Ukraine is important. With this Calculation of cost indicators for RSC options of the Armed Forces of Ukraine could be made:

$$C_j = C_j^{crtn} + C_j^{main} + C_j^{app} \tag{10}$$

Assessment of the sufficiency of financial resources ensures the effective creation, maintenance and application of RSC options (probability of effective financing of the development of RSC option):

$$P_j^{fin} = C_j^{press} / C_j^{ness} \Rightarrow \left\| P_j^{fin} \right\| = \| P_1^{fin} \dots P_j^{fin} \| \tag{11}$$

Collection, analysis, and evaluation of information on the availability (need to create), the state of weapon component samples of certain RSC options and the establishment of time intervals to bring them into combat readiness (depends on the economic capabilities of the state (12). Clarification of the requirements for time intervals for bringing of certain RSC options into combat readiness (13):

$$T_j^{fact} = f(C_j^{press}) \tag{12}$$

$$T_j^{ness} = f(IDP) \tag{13}$$

Assessment of the state's ability to develop create certain RSC option in the necessary time: the probability of timely creation of RSC option:

$$P_j^{T_j} = T_j^{fact} / T_j^{ness} \Rightarrow \left\| P_j^{T_j} \right\| = \| P_1^{T_1} \dots P_j^{T_j} \| \tag{14}$$

Estimation of the probability of occurrence of significant i-th volumes of tasks for application of certain options of RSC of the AF of Ukraine (expert method) $P_i = f\,(IDP)$ (expert survey method – average method) could be done with determining the contribution coefficients of assessments of combat efficiency $\beta_j(P_j^{MC})$, adequacy of financial resources $\beta_j(P_j^{T_j})$, and the ability of the state to create an RSC option within the specified time $\beta_j(P_j^{fin})$ in the overall assessment of the choice of the priority RSC option (based on the results of expert survey)

$$\beta_j(P_j^{MC}) + \beta_j(P_j^{T_j}) + \beta_j(P_j^{fin}) = 1 \tag{15}$$

Experts' completion of matrices of pair comparisons of i-th volumes of tasks for application of certain options of RSC of the AF of Ukraine ($l = \overline{1, L}$ – serial number of the expert with L) and practical calculation of coefficients characterising probabilities of occurrence of various volumes of performance of combat tasks

$$\beta_i^l = \left\| \begin{matrix} \beta_{11}^l & \beta_{12}^l & \cdots & \beta_{1j}^l \\ \beta_{21}^l & \beta_{22}^l & \cdots & \beta_{2j}^l \\ \cdots & \cdots & \cdots\cdot & \\ \beta_{i1}^l & \beta_{i2}^l & \cdots & \beta_{ij}^l \end{matrix} \right\| \Rightarrow \beta_i^l = \sqrt[I]{\prod_{i=1}^{i} \beta_{ij}^l}, (i = \overline{1, I}) \Rightarrow \beta_i^l = \beta_i^l / \sum_{i=1}^{I} \beta_i^l \Rightarrow \beta_i = \frac{1}{L} \cdot \sum_{l=1}^{L} \beta_i^l \Rightarrow \| P_i \| = \left\| \begin{matrix} P_2 \\ \cdots \\ P_i \end{matrix} \right\| \tag{16}$$

Gives calculation of elements of the payment matrix of states $\|W_{ij}^t\|$of efficiency of combat mission by possible RSC options taking into account estimations of sufficiency of financial resources for maintenance of effective creation, development and application of option RSC, estimations of probability of occurrence outstanding i-th scope of tasks for the application of certain RSC options and assessments of the state's ability to create and develop RSC in the necessary time, i.e., to bring it into combat readiness to perform tasks in the t-th year (formula of full probability):

$$d_{ij} = \beta_j(P_j^{MC}) \cdot P_{ij1}^{MC} + \beta_j(P_j^{T_j}) \cdot P_j^{T_j} + \beta_j(P_j^{fin}) \cdot P_j^{T_j}, \sum_j \beta_j = 1 \tag{17}$$

To create a mathematical model of substantiation of the decision on the choice of a rational RSC option of the AF of Ukraine in the conditions of uncertainty of combat tasks of its application, with recommendations on the application of the mathematical model for substantiation of the decision on the choice of the rational RSC option of the AF of Ukraine in the conditions of uncertainty of combat tasks of its application and recommendations on the determination of the calculation algorithm, clarification of the payment matrix of states $\|W_{ij}^t\|$ of the efficiency of the combat mission by possible RSC options, considering assessments of the adequacy of financial resources to ensure effective creation, development and application of the RSC option, assessments of the state's ability to create and develop an RSC option must be made (probability of timely RSC creation):

$$\|W_{ij}^t\| = \left\| \begin{matrix} A/B & B_1 & B_2 & \dots & B_j \\ A_1 & d_{11} & d_{12} & \dots & d_{i1j} \\ A_2 & d_{21} & d_{22} & \dots & d_{2j} \\ A_3 & d_{31} & d_{32} & \dots & d_{3j} \\ \dots & \dots & \dots & d_{ij} & \dots \\ A_1 & d_{i1} & d_{i2} & \dots & d_{ij} \end{matrix} \right\| \quad (18)$$

where ($d_{ij} = f(P_{ij1}^{MC}, P_j^{T\,j}, P_j^{fin})$ – elements of the payment matrix)

With data above final clarification of the payment matrix of states $\|W_{ij}^t\|$ of the efficiency of the combat task with possible RSC options, taking into account the probability of significant i-th volumes of tasks for the application of certain RSC options of the AF of Ukraine could be done,

$$\|W_{ij}^t\| = \left\| \begin{matrix} A/B & B_1 & B_2 & \dots & B_j \\ A_1 & a'_{11} & a'_{12} & \dots & a'_{i1J} \\ A_2 & a_{21} & a_{22} & \dots & a'_{2J} \\ A_3 & a_{31} & a_{32} & \dots & a'_{3J} \\ \dots & \dots & \dots & a_{ij}^{MC} & \dots \\ A_i & a'_{i1} & a'_{i2} & \dots & a'_{IJ} \end{matrix} \right\| \quad (19)$$

where ($a_{ij} = P_i \cdot d_{ij}$ – elements of the payment matrix):

Results of analysis of the payment matrix of states $\|W_{ij}^t\|$ of the efficiency of the combat mission with possible options of the RSC of the AF of Ukraine for the t-th year

$$\|W_{ij}^t\| = \left\| \begin{matrix} A/B & B_1 & B_2 & \dots & B_j \\ A_1 & a'_{11} & a'_{12} & \dots & a'_{i1J} \\ A_2 & a_{21} & a_{22} & \dots & a'_{2J} \\ A_3 & a_{31} & a_{32} & \dots & a'_{3J} \\ \dots & \dots & \dots & a'_{iJ} & \dots \\ A_i & a'_{i1} & a'_{i2} & \dots & a'_{IJJ} \end{matrix} \right\| \quad (20)$$

With it search for a saddle point in the state matrix, where $\alpha = \max_i \min_j a_{ij}, \beta = \min_i \max_j a_{ij}$ – lower and upper price of the game could be made $\alpha = \beta$, and if it false, then A_i^t, B_j^t – dominant strategies on the *t*-th year $N(A,B)_{max} = 2$ and choice of two $N = 2$ dominant strategies for *t*-th year is right. If $\alpha = \beta$ is true, then game strategies A and B are optimal at the Equations (25).

With reduction of the state matrix to the 2X2 matrix according to the dominant strategies (Equation 21)

$$\|W'^{t}_{ij}\| = \left\|\begin{matrix} A/B & B_1 & B_2 & \dots & B_j \\ A_1 & a^t_{11} & a^t_{12} & \dots & a^t_{1j} \\ A_2 & a^t_{21} & a^t_{22} & \dots & a^t_{2j} \\ A_3 & a^t_{31} & a^t_{32} & \dots & a^t_{3j} \\ \dots & \dots & \dots & a^t_{ij} & \dots \\ A_i & a^t_{i1} & a^t_{i2} & \dots & W^t_{IJ} \end{matrix}\right\| \Rightarrow \|W^t_{ij}\| = \left\|\begin{matrix} A'/B' & B'_1 & B'_2 \\ A'_1 & a'^{t}_{11} & a'^{t}_{12} \\ A'_2 & a'^{t}_{31} & a'^{t}_{32} \end{matrix}\right\| \quad (21)$$

calculation of probabilities of dominant strategies for $A\ (P1, P2)$ and $B\ (Q1, Q2)$ for the *t*-th year could be done (Equations 22, 23).

$$P_1 = \frac{a'^{t}_{22} - a'^{t}_{21}}{(a'^{t}_{11} + a'^{t}_{22}) - (a'^{t}_{12} + a'^{t}_{21})},\ P_2 = 1 - \mathrm{P}_1 \frac{a'^{t}_{11} - a'^{t}_{12}}{(a'^{t}_{11} + a'^{t}_{22}) - (a'^{t}_{12} + a'^{t}_{21})} \quad (22)$$

$$Q_1 = \frac{a'^{t}_{22} - a'^{t}_{12}}{(a'^{t}_{11} + a'^{t}_{22}) - (a'^{t}_{12} + a'^{t}_{21})},\ P_2 = 1 - \mathrm{P}_1 \frac{a'^{t}_{11} - a'^{t}_{12}}{(a'^{t}_{11} + a'^{t}_{22}) - (a'^{t}_{12} + a'^{t}_{21})} \quad (23)$$

Selection of the optimal strategy for the RSC option of the AF of Ukraine for the t-th year. If $P_1 \geq P_2$ true then A'_2 and Equations 26, 27 must be used. If false, then A'_2 Equation 24 could be proceeded.

If $Q_1 \leq Q_1$ true then B'_1 and Equations 26, 27 must be used. If false, then B'_2 Equation 24 could be proceeded.

With these results determining the price of the game (the value of the validity of the choice) of RSC option according to the state matrix $|W'^{t}_{ij}|$ must be done.

$$C(A/B) = \frac{a'^{t}_{22} \cdot a'^{t}_{11} - a'^{t}_{21} \cdot a'^{t}_{12}}{(a'^{t}_{11} + a'^{t}_{22}) - (a'^{t}_{12} + a'^{t}_{21})} \quad (24)$$

If determination of the optimal substantiated RSC option of the AF of Ukraine for the t-th year or for the period T (Equation 25) is correct, a^t_{22} – optimal solution.

$$\|W'^{t}_{ij}\| = \left\|\begin{matrix} A'/B' & B'_1 & B'_2 \\ A'_1 & a'^{t}_{11} & a'^{t}_{12} \\ A'_2 & a'^{t}_{21} & a'^{t}_{22} \end{matrix}\right\| \Rightarrow \|W^t_{ij}\| = \left\|\begin{matrix} A/B & B_1 & B_2 & \dots & B_j \\ A_1 & a^t_{11} & a^t_{12} & \dots & a^t_{1j} \\ A_2 & a^t_{21} & a^t_{22} & \dots & a^t_{2j} \\ A_3 & a^t_{31} & a^t_{32} & \dots & a^t_{3j} \\ \dots & \dots & \dots & \dots & \dots \\ A_i & a^t_{i1} & a^t_{i2} & \dots & a^t_{IJ} \end{matrix}\right\| \quad (25)$$

Then clarification of the composition of the priority option of the RSC of the AF of Ukraine for the period *T* by years and the period *t* of its development. Assessment of the sensitivity and stability of the obtained solution of the problem of choosing the priority RSC option of the AF of Ukraine to change the input data on the composition of the RSC could be done:

$$\mathrm{U} = a^{t\,(T)}_{i\,j} \pm \Delta\omega(a^{t\,(T)}_{i\,j}) \leq a^{t\,(T)}_{i\,j+1} \Rightarrow S = const \quad (26)$$

If:

$$\text{U} = a_{i\,j}^{t\,(T)} \pm \Delta\omega(a_{i\,j}^{t\,(T)}) \leq a_{i\,j+1}^{t\,(T)} \Rightarrow S = var \tag{27}$$

If S = var, the composition of the RSC can be revised and it is possible to choose the option that is closest to the assessment in the case of the introduction of an additional evaluation criterion of approximately equal options

Further, the expert survey procedure should be repeated after a group of competent experts (5 experts) in order to clarify the estimates of the pairwise comparison matrix, that is, the matrix should be reformatted in order to reduce the discrepancy between the estimates of RSC options. Re-formed comparative matrix of RSC options by each *l*-th expert has the form:

$$||A_L|| = \left\| \begin{matrix} & x_{\ 1} & \dots & x_{\ 1j} \\ x_{\ 1} & 1 & a_{\ 12} & a_{\ 2j} \\ \dots & \dots & 1 & \dots \\ x_{\ ij} & 1/a_{\ i1} & 1/a_{\ ij} & 1 \end{matrix} \right\| \tag{28}$$

Based on the obtained expert estimates, a preliminary calculation of the priority coefficients of RSC options for the t-th year or period is carried out without reference to the combat situation (1):

$$A_j^l = \sqrt[I]{\prod_{j=1}^{J} a_{ij}^l}\ ,\ (i = \overline{1,\ I}) \Rightarrow A_j^l = A_i^l \Big/ \sum_{i=1}^{I} A_j^l\ \Rightarrow A_j = \frac{1}{L} \cdot \sum_{l=1}^{L} A_i^l\,, \tag{29}$$

where: A_j – priority coefficients of the i-th RSC option in relation to the j-th option.

To increase the reliability of the obtained results, it is proposed to evaluate various variants of RSC in three components, that is, intelligence tools, enemy targets, and controls are evaluated separately. However, assessment of components is carried out taking into account information from experts of the whole range of RSCs to assess their compatibility with each other in each of the proposed options. Each *l*-th expert forms evaluation matrices on the efficiency of reconnaissance (control, attack) of the j -th RSC option for different volumes of combat mission performance ($i \in [1;5]$) ($P\,_{i\,j}^{1,2,3}$ – probability of reconnaissance (control, attack) of a given number of enemy objects of the i-th option) (30) [7]:

$$||P^{k=1,2,3}|| = \left\| \begin{matrix} & N_{\ 1} & \dots & N_{\ j} \\ V_{\ 1} & P\,_{11}^{1,2,3} & P\,_{12}^{1,2,3} & P\,_{1j}^{1,2,3} \\ \dots & P\,_{i1}^{1,2,3} & P\,_{i2}^{1,2,3} & \dots \\ V_{\ j} & P\,_{i1}^{1,2,3} & P\,_{i2}^{1,2,3} & P\,_{ij}^{1,2,3} \end{matrix} \right\| \tag{30}$$

where: $P\,_{i\,j}^{3}$ – probability of damaging enemy objects is considered a fulfilled condition for 70-80% of the affected objects from the entire enemy composition.

Based on the results of an expert survey, a general evaluation of the efficiency of implementation of i-th combat task with a certain composition of the j-th option of RSC for each *l*-th expert is formed, that is, a general estimate of the probability of performing combat mission with j-th RSC option is formed according to the opinion of *l*-th expert: $P_{i\,j}^{\overleftrightarrow{l}\ CM} = \text{P}\,_{i\,j}^{\overleftrightarrow{l}\ 1} \cdot \text{P}\,_{i\,j}^{\overleftrightarrow{l}\ 2} \cdot \text{P}\,_{i\,j}^{\overleftrightarrow{l}\ 3}$. In other words, the survey results of each expert allow creating a common payment matrix of states $\|W_{i\,j}^{t}\|$ efficiency of performing a combat mission according to possible enemy strategies (A) and possible RSC options (B) for the entire expert group $l = \overline{1, L}$ (31):

$$\|W_{i\,j}^{t}\| = \begin{Vmatrix} A/B & B_1 & B_2 & \dots & B_j \\ A_1 & P_{1\,1}^{CM} & P_{12}^{CM} & \dots & P_{i1j}^{CM} \\ A_2 & P_{21}^{CM} & P_{22}^{CM} & \dots & P_{2\,j}^{CM} \\ A_3 & P_{3\,1}^{CM} & P_{32}^{CM} & \dots & P_{3\,j}^{CM} \\ \dots & \dots & \dots & P_{i\,j}^{CM} & \dots \\ A_i & P_{i1}^{CM} & P_{i2j}^{CM} & \dots & P_{i\,j}^{CM} \end{Vmatrix} \tag{31}$$

where: ($P_{i\,j}^{CM}$ – elements of the payment matrix – general estimates of the efficiency of performing a combat mission (CM) for the entire expert group are calculated as: $P_{i\,j}^{CM} = \frac{1}{L} \cdot \sum_{l=1}^{L} P_{i\,j}^{l\rightleftarrows\,CM}$. The resulting payment matrix allows, assuming that all options of enemy actions (strategies of party A) are equivalent, to calculate the arithmetic mean of the total efficiency of all possible enemy strategies, and get preliminary results on the priority of th j-th options of RSC according to estimates of their combat efficiency: $P_{i}^{CM} = \frac{1}{J} \cdot \sum_{j=1}^{J} P_{i\,j}^{CM}$, where P_{i}^{CM} – evaluation of the efficiency of performing a combat mission with j-th RSC option; $P_{i\,j}^{CM}$ – evaluation of the efficiency of performing combat mission with j-th RSC option for the i-th option of enemy actions (composition of enemy forces and means) (Table 2).

Table 2 – General results of evaluating the efficiency of RSC options for the entire expert group

No.	RSC options / Number of enemy objects to attack	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
1	**(0 - 20)**	0.79	0.90	0.81	0.89	0.77	0.85
2	**(20 - 40)**	0.75	0.80	0.79	0.85	0.73	0.77
3	**(40 - 60)**	0.70	0.79	0.73	0.78	0.68	0.70
4	**(60 - 80)**	0.67	0.76	0.69	0.75	0.65	0.64
5	**(80 - 100)**	0.64	0.71	0.62	0.73	0.64	0.60
Overall average score		0.71	0.79	0.73	0.80	0.69	0.71
Priority coefficients		0.160	0.179	0.164	0.181	0.156	0.160

But the methodology involves taking into account the effects of many factors. The influence of these factors is taken into account when clarifying the mathematical model for choosing a rational RSC option.

An assessment of the impact of the economic criterion on the choice of a rational RSC option is carried out. Assessment of the sufficiency of the economic (resource) capabilities of the state to create and maintain each j-th RSC option:

$$C_{j}^{req} = C_{j}^{creat} + C_{j}^{maint} + C_{j}^{appl} \tag{32}$$

where: C_{j}^{creat}, C_{j}^{maint}, C_{j}^{appl} – the cost of the creation, maintenance, and application of the j-th RSC option.

Further, the sufficiency of financial resources to ensure the creation, maintenance, and application of the selected RSC option is assessed (the probability of effective financing for the development of the RSC option): $\mathrm{P}_j^{fin} = \mathrm{C}_j^{cap}/\mathrm{C}_j^{req} \Rightarrow \|\mathrm{P}_j^{fin}\| = \|\mathrm{P}_1^{fin} \;\; \ldots. \;\; \mathrm{P}_j^{fin}\|$, where C_j^{cap} – resource capabilities of the state to develop the j-th RSC option; C_j^{req} – the cost of the required financial resources to develop the j-th RSC option.

Next, information is collected, analysed, and evaluated regarding the need of the Armed Forces of Ukraine for additional creation of samples of military equipment, which are components of certain RSC options and time intervals to bring them to combat readiness, that is, an assessment of the dependence of their creation and bringing to combat readiness, taking into account the sufficiency of the economic capabilities of the state $T_j^{fact} = f(C_j^{pos})$. The presence in the Armed Forces of Ukraine of samples of military equipment (elements) that are part of the RSC options reduces the time and volume of financial resources to bring a certain RSC options to combat readiness, and the need to create separate elements of RSC options, on the contrary, increases the time and volume of financial resources to bring them into combat readiness to perform certain tasks [8], [9].

The next step of the methodology is to determine or clarify the requirements for time intervals for bringing the proposed RSC options to combat readiness $\mathrm{T}_j^{req} = f$. Required time to bring the RSCs to combat readiness (T_j^{req}) is a function of the military and political situation around Ukraine. Assessment of the ability of the state to create and bring the RSCs to combat readiness in the required time frame is carried out by an indicator of the probability of timely creation and combat readiness of each variant of RSC: $\mathrm{P}_j^{\mathrm{T}j} = \mathrm{T}_j^{fact}/\mathrm{T}_j^{req} \Rightarrow \left\|\mathrm{P}_j^{\mathrm{T}j}\right\| = \left\|\mathrm{P}_1^{\mathrm{T}_1}, \;\; \ldots., \;\; \mathrm{P}_j^{\mathrm{T}j}\right\|$, where T_j^{fact} – the actual time required to create and bring to combat readiness. These are requirements conditioned by the military-political situation and threats to the state, which may cause the need for joint forces operations; T_j^{req} – the required time for creating and bringing to combat readiness of the j-th RSC option is the minimum possible time for creating and delivering each specific option of RSC to the Armed Forces of Ukraine. Next, it is necessary to determine the coefficients of contributions to the overall assessment of the choice of a rational RSC option: $\beta_j(P_j^{MC})$ – contribution coefficient of combat efficiency assessments of RSC options; $\beta_j(P_j^{fin})$ – contribution coefficient of assessment of sufficiency of financial resources of the state for creation, maintenance, and application of each j-th RSC option; $\beta_j\left(P_j^{T\,j}\right)$ – contribution coefficient of assessments of the state's ability to create and bring each j-th FSC option to combat readiness within a certain time frame (timeliness factor) (5):

$$\beta_j(P_j^{MC}) + \beta_j\left(P_j^{T\,j}\right) + \beta_j(P_j^{fin}) \tag{33}$$

The calculation of contribution coefficients is carried out by a certain expert group by filling in matrices of paired comparisons of i-th volumes of tasks for the application of certain variants of RSC of the Armed Forces of Ukraine. Practical calculations carried out for the selected RSC options showed that the largest contribution coefficient (importance in the overall final mathematical model of decision-making) have estimates of the combat efficiency of RSCs at the level of 56.3% of the total assessment. The estimates of the sufficiency of resources to ensure the creation, maintenance, and application of RSCs at the level of 23.2% and estimates of the ability of the state to timely create RSCs have contribution coefficients at the level of 20.5%. After determining the contribution coefficients and calculating the impact of estimates of resource sufficiency and timeliness of bringing various RSCs to combat readiness, it is necessary to clarify the elements of the payment matrix $\|W_{i\ j}^{t}\|$ (34):

$$d_{i\ j} = \beta_j\left(P_j^{MC}\right) \cdot P_{i\ j1}^{MC} + \beta_j\left(P_j^{T_j}\right) + \beta_j\left(P_j^{fin}\right) \cdot P_j^{T_j}, \sum_j \beta_j = 1 \tag{34}$$

Next, a mathematical model is formed to substantiate the decision to choose a rational option of RSC in conditions of uncertainty of its application. The payment matrix of states is clarified $\|W_{i\ j}^{t}\|$ the effectiveness of the implementation of the i-th combat task by possible j-th RSC options taking into account the estimates of the sufficiency of financial resources (economic capabilities of the state) to ensure the effective creation, maintenance, and application of RSCs, estimates of the ability of the state to timely create and develop the RSC, where the matrix elements are calculated according to equation 5 based on the estimates of the combat efficiency of the use of RSC (3), and taking into account the contribution coefficients of each assessment indicator to the overall assessment of the priority of RSC options among themselves (35):

$$\|W_{i\ j}^{t}\| = \left\| \begin{matrix} A/B & B_1 & B_2 & \dots & B_j \\ A_1 & d_{1\ 1} & d_{12} & \dots & d_{i1j} \\ A_2 & d_{21} & d_{22} & \dots & d_{2\ j} \\ A_3 & d_{3\ 1} & d_{32} & \dots & d_{3\ j} \\ \dots & \dots & \dots & d_{i\ j} & \dots \\ A_i & d_{i1} & d_{i\ 2} & \dots & d_{IJ} \end{matrix} \right\| \tag{35}$$

where: ($d_{i\ j} = f\left(P_{ij1}^{CM}, P_j^{T_j}, P_j^{fin}\right)$ – elements of the payment matrix)

Analysis of the results obtained shows that the RSC option No. 5 loses its position relative to the pre-defined priority, because it significantly loses to options with a lower cost of creation, and most importantly, it requires the most time for creation and putting to combat readiness. The highest priority according to the overall average estimates of the implementation of all those tasks defined in Table 3 is acquired by the 2nd RSC option and the next one is the 4th option. The difference in the priority of these options according to the calculated indicators of the efficiency of combat use and restrictions on the creation and maintenance of RSCs is only 2%. The difference in the priority of Option 4 and Option 5, which was the best in terms of combat efficiency, is more than 14%. The obtained results of the calculated elements of the payment matrix are the basis for making decisions on choosing a rational RSC option in the current situation (Table 3) [10].

Table 3 – Payment matrix for evaluating the efficiency of the use of RSC options, taking into account the influence of factors of sufficient financial resources and timeliness in bringing them to combat readiness for the t-th year

No.	RSC options / Number of enemy objects to attack	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	min max	The probability of occurrence of tasks of different volumes
1	**(0 - 20)**	0.60	0.68	0.61	0.67	0.58	0.65	0.68	0.76
2	**(20 - 40)**	0.65	0.70	0.68	0.74	0.63	0.67	0.74	0.87

3	**(40 - 60)**	0.68	0.76	0.70	0.75	0.65	0.67	0.76	0.96
4	**(60 - 80)**	0.55	0.62	0.57	0.62	0.53	0.52	0.62	0.82
5	**(80 - 100)**	0.45	0.50	0.44	0.52	0.46	0.42	0.52	0.71
	max min	0.45	0.50	0.44	0.52	0.46	0.42		
Priority coefficients		0.160	0.179	0.164	0.180	0.156	0.160		
Overall average score		**0.59**	**0.65**	**0.60**	**0.66**	**0.57**	**0.59**	**0.61**	

The calculation results show that according to arithmetic mean estimates, the second option is the highest priority for performing the entire range of tasks, the overall estimates of the priority of options have not changed (Table 4, Fig. 1) [11], [12].

The last step of the proposed methodology for assessing the sensitivity and stability of the obtained solution to the problem of choosing a priority RSC option before changing the input data on the composition of RSCs:

$$U = a_{ij}^{t(T)} \pm \Delta\omega\left(a_{ij}^{t(T)}\right) \leq a_{ij+1}^{t(T)} \Rightarrow S = const, \text{ if } U = a_{ij}^{t(T)} \pm \Delta\omega\left(a_{ij}^{t(T)}\right) \leq a_{ij+1}^{t(T)} \Rightarrow S = var \quad (36)$$

If $S = var$ the composition of RSC can be revised and it is possible to choose the option that is closest in rating if an additional criterion for evaluating approximately equal options is introduced [13], [14], [15].

Table 4 – Final payment matrix for solving the problem of choosing a rational RSC option under various conditions of using enemy troops in an operation

No.	Number of enemy objects to hit simultaneously	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
1	(0-20) (2-3 tank or mechanised companies)	0.60	0.68	0.61	0.67	0.58	0.65
2	(20-40) (1 tank regiment or 2-3 mechanised companies)	0.65	0.70	0.68	0.74	0.63	0.67
3	(40-60) (1 tank regiment or 1 mechanised brigade)	0.68	0.76	0.70	0.72	0.65	0.67
4	(60-80) (1 tank or mechanised brigade + 1 tank regiment)	0.55	0.62	0.57	0.60	0.53	0.52
5	(80-100) (1-2 tank or mechanised brigades)	0.45	0.52	0.44	0.49	0.46	0.42
	Overall average score	**0.59**	**0.66**	**0.60**	**0.65**	**0.57**	**0.59**

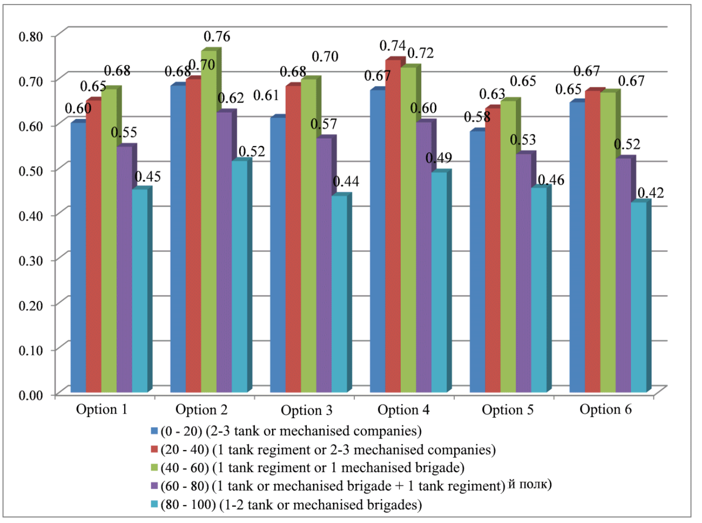

Fig. 1 – Results of evaluating the priority of RSC options for various combat tasks, taking into account the results of assessing the probability of occurrence of RSC tasks for options of enemy action during the T-th period

4. CONCLUSIONS

The methodology proposed by this study would increase the validity of decisions on the use of reconnaissance-strike complexes and systems of the Armed Forces of Ukraine and the reliability of results on assessing the efficiency of their use and the sufficiency of material and financial resources for the creation, maintenance, and application of such complexes and systems. The findings would contribute to improving the level of development of the Armed Forces of Ukraine as a whole and the efficiency of using public funds in conditions of limited financial resources for their development. The prospect of the further study on the subject is the development of recommendations for the practical application of the proposed methodology in the defence planning system of Ukraine for the selection of various complex systems of WME in the development programmes of the Armed Forces of Ukraine.

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