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DEVISING A PROCEDURE FOR JUSTIFYING THE CHOICE OF RECONNAISSANCE-FIRING SYSTEMS

O. Maistrenko
Doctor of Military Sciences, Leading Researcher*
E-mail: maj_Alex@ukr.net
V. Khoma
PhD, Associate Professor, Head of Center*
E-mail: vitkhom67@gmail.com
O. Karavanov
Adjunct
Scientific and Organizational Department**
E-mail: karavanov77@gmail.com
S. Stetsiv
PhD, Senior Lecturer
Department of Missile Forces**
E-mail: stanislav13@meta.ua
A. Shcherba
PhD, Senior Lecturer
Department of Complexes and Devices
of Artillery Recconaissance**
E-mail: shch_ay@ukr.net
*Scientific and Methodical Center of Organization
of Scientific and Scientific and Technical Activity
The National Defence University of Ukraine
named after Ivan Chernyakhovskyi
Povitroflotskyi ave., 28, Kyiv, Ukraine, 03049
**Hetman Petro Sahaidachnyi National Army Academy
Heroiv Maidanu str., 32, Lviv, Ukraine, 79026

This paper reports a study into the special features of military (combat) activities at the present stage of military art development. The purpose was to subsequently define the basic requirements for reconnaissance-firing systems. The features under consideration are a rapid change in the situation, competition with an enemy for winning in time, accuracy, maneuverability, secrecy. They also involve a large amount of data that must be operated when deciding on combat use (hostilities). Other attributes of modern military (combat) activities are the consistency of operations and a clear structure of subordination; independence in maintenance and positioning. These data are useful and important because they make it possible to reasonably define the requirements for reconnaissance-firing systems.

This paper has defined those requirements for reconnaissance-firing systems and such criteria for their selection that are predetermined by the specificity of military (combat) activities. The most important selection criteria include efficiency, accuracy, secrecy, robustness.

Several actual reconnaissance-firing systems have been analyzed in order to demonstrate the use of the methodology. Specifically, «Kropyva» (Ukraine), «ArtOS» (Ukraine), «Obolon-A» (Ukraine), «Sokil» (Poland, Ukraine).

A procedure for justifying the choice of reconnaissance-firing systems has been devised, taking into consideration the conditions of military (combat) activities, based on the method involving an analytic hierarchy process. A given procedure substantiates those selection criteria that were determined on the basis of patterns in modern military activities.

From a practical point of view, the proposed methodology makes it possible to significantly reduce the time for planning an operation and considerably improve the validity of decisions by a commander (chief) regarding the choice of a reconnaissance-firing system and its further use in combat activities

Keywords: reconnaissance-firing systems, military (combat) activities, hierarchy analysis method

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1. Introduction

The results of the analysis of military conflicts in recent decades convincingly indicate the growing role of reconnaissance-firing systems (RFS). Thus, from Operation Desert Storm in 1991 [1] to the ATO Anti-Terrorist Operation (Joint Forces Operation) in eastern Ukraine [2, 3] the share of targets hitting has increased from 10–30 % to 50–90 %.

However, the increasing involvement of RFS in the implementation of tasks has revealed a series of issues that affect the effectiveness of their application.

Thus, one of the problems is to equip RFS with elements that have different capabilities. Namely, the inclusion of field artillery in RFS (such as missile forces and artillery), which can execute tasks at the intensity and probability of fulfillment far exceeding the capabilities of reconnaissance [4]. Or the involvement of so many intelligence tools that significantly outweigh the throughput of control and data transfer units [5].

Another issue is a relatively rapid change in the characteristics of targets in terms of mobility, secrecy, the ability to actively counteract. That manifests itself in that over a relatively short period (even up to several days) the target can be modified so that the existing means of hitting it become impractical [1, 3–5].

The next significant problem, according to the authors of [5], is the lack of (not sufficient consideration) RFS functioning stability. Quite often, when planning military (combat) activities, only static counteraction of the enemy is taken into consideration, that is, one that depends only on the capabilities of the enemy without taking into consideration the actions [1, 3–7].

If these issues occur at the same time, they can completely neutralize the positive effect of using RFS and, in general, lead to organizational challenges. Such issues include the difficulty of choosing the most important RFS characteristics, the inability to determine the justified advantage of a certain RFS over another. Therefore, it is a relevant task to devise a procedure for such substantiation, given the growing role of RFS in conducting military (combat) operations.

2. Literature review and problem statement

Study [8] analyzes in detail the Russian Federation's RFS and their elements and defines their capabilities and characteristics. In particular, the authors considered the following elements: artillery fire control system 1B12 «Harkov», portable radar station 1L120 «Credo-M1», portable counter-fire radar station 1L271 «Aistenok», PRP-4A Argus, counter-fire radar station 1L219M «Zoopark-1M», radar station 1RL232-2M «SNAR-10M1», unmanned aerial vehicles: Orlan 10, Granat-4, Eleron-3SV. They analyzed the basic organizational and staff structures of RFS and characterized the main functional links among these structures. The methods of target acquisition were described. Although the study highlights the main requirements for RFS, based on which would-be RFS are to be designed (selected), the authors, however, disregarded approaches to such a choice.

Article [9] discusses the development of RFS elements such as artificial intelligence and unmanned aerial vehicles. A detailed analysis of the existing development programs of these fields in China compared to the USA is given. Interesting in the cited article is the forecasting of the conditions for the use of RFS in future combat (military) activities. However, the article lists only general methodological approaches to the design (choice) of would-be RFS.

Paper [10] highlights an approach to improving the effectiveness of rocker forces and artillery units by building RFS. The paper defines the indicators and the general procedure for their calculation based on the model of a generalized consumer of information. In addition, the proposed model establishes the dependence of RFS efficiency on the composition and characteristics of its components. The paper considers only one RFS component – reconnaissance, and only one type of it, an unmanned aircraft complex, which significantly narrows the scope of the methodological approaches described. Although the mathematical model of the generalized RFS consumer proposed in the paper makes it possible to evaluate the effectiveness of RFS but only by productivity, given the relative number of destroyed objects:

$$W = \frac{M(n)}{N}, \quad (1)$$

where $M(n)$ is the mathematical expectation of the number of destroyed objects; N is the total number of objects identified for destruction.

The use of that dependence could lead to significant inaccuracies without additional consideration of the stability of RFS functioning.

Study [11] categorized existing RFS and introduced a new concept of «Situational reconnaissance and strike complex», as well as identified trends in the development of RFS and problems in their operation. In particular, the study defines ways to overcome the identified issues. One of the problems is the exclusion of information redundancy and oversaturation of data in the RFS control tools. Another issue is to eliminate contradictions and uncertainties in information for its unambiguous understanding. In addition, the problems are the organization of internal, in relation to the complex, information exchange; increasing the survivability of RFS and the robustness of its control system. However, the cited study does not substantiate the requirements for RFS, which leads to the impossibility of determining exactly those properties that most significantly affect the functioning of RFS during combat (military) activities. Although the study reasonably substantiates the need to design (choose) a situational RFS, however, there are no methodological approaches to justifying the choice of RFS for certain conditions.

Paper [12] highlighted the issue of improving intelligence in the interests of missile forces and artillery. In particular, the paper proposes the following ways: to improve the tactics and technical characteristics of RFS components and techniques to process intelligence information. The paper does not consider what kind of tactics and technical characteristics need to be improved, what exactly affects the effectiveness of the use of RFS regarding the ways of information processing. Moreover, the cited paper also lacks methodological approaches to the choice of RFS.

Article [13] discusses the role of RFS in the implementation of new network-centric concepts of combat (military) activities. In addition, the authors described their variant of the use of RFS. However, the article does not provide a mechanism for justifying the choice of RFS depending on conditions.

Study [14] addresses the issue of RFS classification and identifies some issues related to their use. It is proposed to increase the capabilities of the reconnaissance subsystem, to identify enemy objects as one of the ways to solve the identified problems. It is also proposed to improve the level of automation of combat operations by firing means, processes of preparation, firing, and tactical autonomy. The authors also noted the need to build an automated control system that would enable real-time control over enemy destruction. In addition, they noted the need to ensure the joint stable functioning of all elements of the system under the conditions of information redundancy and oversaturation of data in the means of control. However, no relationship between these problems and ways to solve them was shown. The set of RFS properties, which are the most important depending on the conditions of military (combat) activities, was not determined.

Although the above studies made a significant contribution to the development of theoretical approaches to the use of RFS, they, however, did not consider the issue of justifying the choice of RFS taking into consideration the conditions of military (combat) activities.

Regarding the selection of a method that would provide both a justified and simple solution to the multicriteria problem of choice, it is proposed to consider the methods of cluster analysis, the analysis of hierarchies, as well as expert evaluation [15–18].

The results of analyzing previous studies [19] indicate that the specified methods are quite popular among researchers and are used in various fields of science.

Thus, the Analytic Hierarchy Process method and an expert evaluation method were applied in study [19]. Based on these methods, the cited study devised a procedure for improving the effectiveness of solving the multicriterial problem of capacity assessment in defense planning. In the study, the hierarchy analysis method was used to conduct an expert assessment of capabilities via comparing them pairwise according to certain criteria.

Paper [20] developed approaches to improving the methods of testing and conformity assessment of specialized software for measuring equipment. The paper applied a hierarchy analysis method for three levels of requirements for the software tool, which is an interesting, but, according to the authors, a complicated approach to compiling the requirements directly within the method.

Study [21] devised a procedure for comparative evaluation of variants of the weapons sample according to a set of characteristics that define its military-technical level. The use of cluster analysis, expert evaluation, and a hierarchy analysis method in the cited study is due to the need to operate a relatively large number of characteristics (requirements).

The methodical apparatus for assessing and managing the environmental safety of solid waste treatment processes through the use of expert and analytical procedures by the comprehensive application of a hierarchy analysis method was improved in [22]. This methodical apparatus comprehensively takes into consideration both the formation of environmental hazards and the justified and defined priorities of the necessary management measures and quantitative expert evaluation.

However, the use of these methods also has a series of limitations. Thus, a cluster analysis method significantly depends on the scale of the measurement of attributes. That is, objects similar in most ways, but having significant differences one by one would be related to different classes, which is not always true.

Regarding the application of a hierarchy analysis method, it should be noted that the result significantly depends on the formalization of criteria. That is, the wrong set of criteria could lead to significant errors in the results. Moreover, it is impossible to check the compliance with the criteria for the purpose of the study. That is, it is impossible to check and correct the results using the method itself.

As regards methods of expert evaluation, it should be noted that these methods have a high level of subjectivism. That is, the judgments by one expert have certain errors, and the coordination of the judgments by several experts without the consent of their competence could lead to even greater errors. At the same time, determining the competence and coordination of expert judgments significantly complicates the computation and increases the likelihood of making mistakes.

Thus, the results of our analysis of the literary data indicate a number of problems associated with studying the use of RFS. Thus, one of the most significant issues is the lack of methodological approaches to justifying the choice of RFS for certain conditions. Another problem is the lack of properties (selection criteria) of RFS, which are most important depending on the conditions of military (combat) activities.

In addition, the analysis of methods for solving multicriteria problems has revealed a series of problems associated with their application. Thus, the considered methods, when using them separately, would predetermine the high computational complexity, uncertainty in the formalization of input data, the subjectivism of the results.

Based on this, it becomes possible to state a scientific problem. Its essence is the absence of a scientific and methodological apparatus for justifying the choice of RFS, which could take into consideration the predefined conditions and would be based on such a combination of methods that could minimize errors.

3. The aim and objectives of the study

The aim of this study is to devise a procedure for justifying the choice of RFS taking into consideration the conditions of military (combat) activities. That would make it possible to increase the validity of the decisions by a commander (chief) regarding the choice of a reconnaissance-firing system and its further use in combat activities.

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

– to formalize the procedure for justifying the choice of RFS;

– to define the input data for the procedure of justifying the choice of RFS;

– to analyze the results of calculating an example of the application of the procedure for justifying the choice of RFS.

4. Materials and methods to study the process of selection of reconnaissance-firing systems

Microsoft Excel 2010 software was used for calculations.

To substantiate the properties (selection criteria) of RFS, which are the most important depending on the conditions of military (combat) activities, a cluster analysis method was used. The method of cluster analysis implies splitting a given sample of objects into subsets (clusters) so that each cluster consists of similar objects while objects from different classes differ significantly [15].

To obtain reasonable data on the priority of criteria to select and specify RFS, an expert evaluation method was used. The method of expert evaluation implies identifying a generalized assessment of the expert group by analyzing and processing individual independent assessments by experts who are part of the group [18]. Since an expert survey is a quantitative method of research, the number of persons in an expert group typically does not significantly affect the result. Therefore, a group of experts should not be too large, in order to be able to form a consolidated opinion as a result of the survey. An important factor when choosing experts is their competence.

Next, by ranking, the normalized coefficients of the importance of expert judgments were determined. The essence of such ranking is the assessment by an expert of the level of his/her competence and the rest of the experts on the list. Next, generalization and rating expert assessments. Such an approach ensures an impartial determination of the expert's competence and significantly reduces errors of judgments.

In general, an approach to determining the relative competence of experts during the aggregation of pairwise comparisons corresponds to the improved approach proposed in [23]. Thus, the main components of the relative competence coefficient of the β-th member of an expert group C_β are the self-estimate $C_{\beta,c}$, the mutual assessment $C_{\beta,a}$, and the objective component $C_{\beta,o}$. General expression: $C_\beta=C_{\beta,c}(X_1C_{\beta,a}+X_2C_{\beta,o})$, where X_1 and X_2 are the relative weights of the objective and mutual assessment of competence of the members of an expert group [23]. Moreover, the mutual assessment is defined as the indirect value of the judgments by all experts $C_{\beta,a}$. The parameter of the objective component $C_{\beta,o}$ is defined as the normalized value of such indicators as education and experience.

It should also be noted that a «snowball» approach was applied when selecting experts. The approach implies that the list of experts is compiled on the basis of recommendations from experts already included in the list [23]. This suggests that the weight coefficients X_1 and X_2 accept the same value of 0.5.

Questionnaires for the survey (Fig. 1, 2) include a pairwise comparison of the criteria for choosing RFS in order to determine the assessments of the vector of priorities. A pairwise comparison of the selected for the example of RVS is performed for each of the criteria. The comparison is performed in accordance with the values for a variant of the scale by T. Saaty [19] (Table 1).

Criterion	Criterion 1	Criterion 2	Criterion 3	Criterion 4
Criterion 1	1.0	1/K12	1/K13	1/K14
Criterion 2	K12	1.0	1/K23	1/K24
Criterion 3	K13	K23	1.0	1/K34
Criterion 4	K14	K24	K34	1.0

Fig. 1. Expert questionnaire for comparing the criteria for choosing RFS to determine the assessments of the vector of priorities

RFS designation	RFS 1	RFS 2	RFS 3	RFS 4
RFS 1	1.0	1/K12	1/K13	1/K14
RFS 2	K12	1.0	1/K23	1/K24
RFS 3	K13	K23	1.0	1/K34
RFS 4	K14	K24	K34	1.0

Fig. 2. Expert questionnaire for comparing RFS in relation to each criterion

Table 1

Variant of the T. Saaty scale

Variants of the name of the assessment in pairwise comparison	Value
Much better/much more important/has an absolute advantage	9
Much better/much more important/has a significant advantage	5
Better/more important/has an advantage	3
A little better/a little more important/has a slight advantage	2
Equal	1

K_{ij} is the value of expert evaluation of the component for the i-th column of the j-th row. Moreover, experts enter data on K_{12}, K_{13}, K_{14}, K_{23}, K_{24}, K_{34}, the rest of the data, according to the essence of the method, are calculated as an inverse value.

The generalization of the data was carried out by averaging judgments using the coefficient of relative competence of the expert as a weight coefficient.

To summarize the expert evaluation data, a hierarchy analysis method was used. The hierarchy analysis method implies the decomposition of the problem into simpler components and further processing, by pairwise comparisons, the sequences of judgments by a decision-maker. As a result, the relative degree (intensity) of the interaction of elements in the hierarchy can be expressed. These judgments are then expressed numerically. The method of hierarchy analysis includes procedures for the synthesis of multiple judgments, obtaining priority criteria, and finding alternative solutions [16, 17].

In accordance with the essence of the method, each expert compared the criteria (efficiency, accuracy, secrecy, stability) in a pairwise manner to determine the vector of priority of the criterion.

Next, we determined the assessment of the component of the eigenvector from the known formula for finding the average geometric value [16, 17, 19–22]:

$$\overline{K}_j = \sqrt[n]{\prod_i^n K_{ij}}, \tag{2}$$

where $\bar{K}_j$ is the evaluation of the eigenvector component for the i-th column of the j-th row; n is the number of columns in the matrix.

Next, we normalized the assessment of the priority vector according to the estimation dependence [16, 17, 19–22]:

$$N_j = \frac{\overline{K_{ij}}}{\sum_j^m \overline{K_{ij}}}, \tag{3}$$

where N_j is the value of the normalized assessment of the priority vector; m is the number of rows in the matrix.

Next, to check the consistency of the opinions by experts, the parameters of the consistency index and the ratio of consistency are determined according to estimation dependences (4), (5). It is necessary to pay attention to the consistency of the expert's judgments. Thus, when the ratio of consistency exceeds 10 %, it is necessary to reconsider the judgment due to a significant discrepancy in the estimates [16, 17].

$$I = \frac{\sum_i^n \left(\sum_j^m K_{ij} \right) N_j - n}{n-1}, \tag{4}$$

where I is the consistency index.

Accordingly, the ratio of consistency is determined [16, 17]:

$$W = \frac{I}{r}, \tag{5}$$

where W is the ratio of consistency; r is the consistency index for a symmetric matrix; for matrix 4×4, this index is 0.9 [16, 17, 19–22].

Next, we determine the global priorities of RFS relative to each of the selection criteria by entering the values of the normalized assessments of the vectors of priorities for RFS in relation to each of the criteria and the normalized assessments of the vectors of the criteria priorities into the table. The calculation of global priorities is carried out according to the known estimation dependence [16, 17, 22]:

$$G_{gp} = \sum_l^L N_p N_l, \tag{6}$$

where G_{gp} is an indicator of the global priority of a certain RFS; l is the number of the selection criterion; L is the number of selection criteria; N_p is the value of the normalized assessment of the priority vector of a certain RFS relative to the selection criterion; N_l is the value of the normalized assessment of the priority vector of a certain selection criterion.

5. Results of studying the process of selection of reconnaissance-firing systems

5. 1. Formalization of the procedure for justifying the choice of RFS

The input data for a given procedure are the information about modern military (combat) activities, information on the tactics and technical characteristics of RFS, the number of experts, and the characteristics of their competence.

At the first step of the procedure, it is proposed to determine the features of military (combat) activities at the present stage of the development of military art. Although this step may have steady results over a long time and can be considered as input data, it is proposed to consider it as a step of the procedure because it is quite difficult to predict a change in the characteristics of activities.

The next step is to define the requirements for RFS predetermined by the peculiarities of modern military (combat) activities. These requirements make it possible to form certain clusters of requirements, which, in the next step of the procedure, will make it possible to determine the properties (selection criteria) of RFS depending on the characteristics of activities.

In the next step, an expert assessment of the criteria for choosing RFS according to the questionnaire (Fig. 1) and generalization of the results in accordance with the number and competence of experts is carried out.

Next, at step 7, we assess the component of the eigenvector of each criterion and normalize the assessment of the priority vector of each criterion in step 8. The next two steps check the consistency of the results obtained. Thus, according to estimation formula (4), the consistency index (step 9) is determined and, in accordance with formula (5), the ratio of consistency (step 10) is determined.

Step 11 checks the condition that the consistency ratio should not exceed 10 %. If this condition is not met, the values are checked; return to step 7. In the case when this condition is met, proceed to step 12. In step 12, a pairwise comparison of RFS is carried out relative to each of the criteria. Moreover, calculations are carried out in accordance with estimation dependences (2) to (5).

In step 13, global priorities are identified to determine RFS rating in accordance with the predefined conditions. Determination of global priorities is carried out according to estimation dependence (6).

The next step is to compare the values of the global priorities of RFS and determine the advantage of a certain RFS relative to other RFS. One can present results as a chart, graph, or table.

A general form of the flowchart of the procedure for justifying the choice of RFS taking into consideration the conditions of military (combat) activities is shown in Fig. 3.

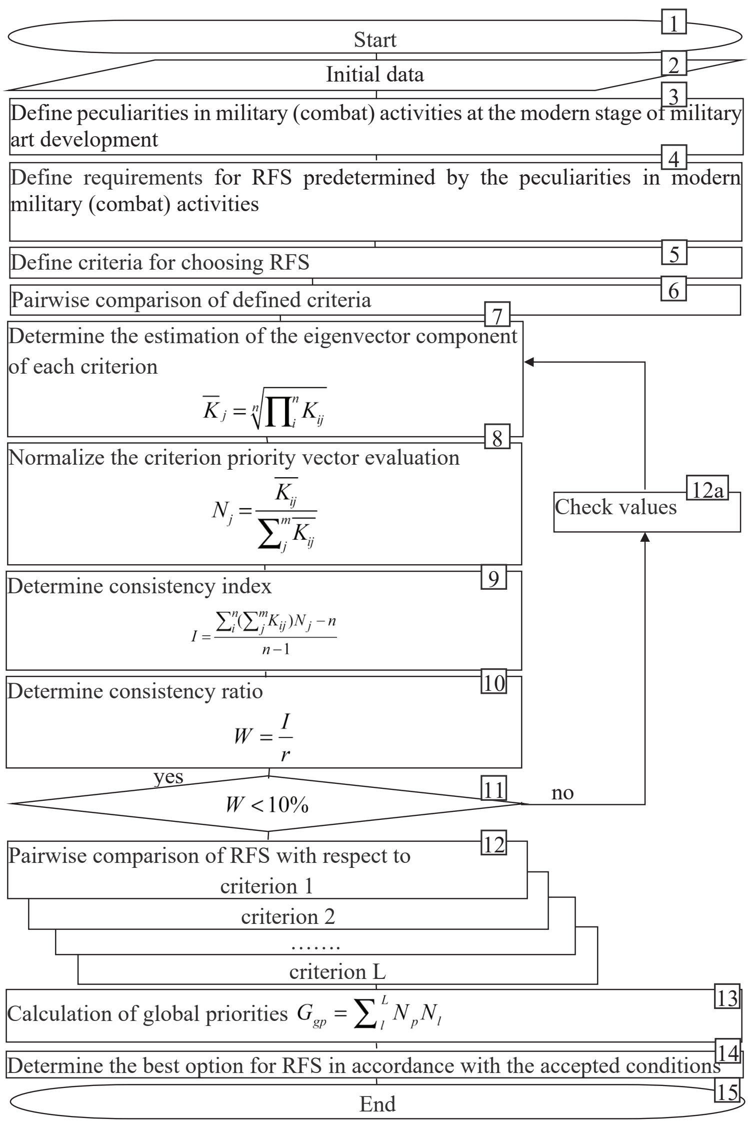

Fig. 3. Flowchart of the procedure for justifying the choice of RFS taking into consideration the conditions of military (combat) activities

5. 2. Formation of input data for the procedure of justifying the choice of RFS

The results of the analysis of military conflicts of recent decades [1–7, 24] and the possible future nature of war [25] make it possible to define those features in the military (combat) activities that significantly affect the use of RFS.

Thus, one of the features is a quick change in the situation. For example, during the operations in Iraq, Afghanistan, the anti-terrorist operation (ATO) (Joint Forces Operation) in the east of Ukraine [1–7, 24, 26], the situation was changing in ranges from a few minutes to several hours. That led to the fact that the control means did not even have time to display up-to-date information. The above directly predetermines an increase in the role of efficiency both in general during the operation and when executing tasks for RFS.

Another feature is a comprehensive competition with an enemy for winning in time, accuracy, maneuverability, secrecy. This feature was demonstrated during the military conflicts in Georgia and the unrecognized republic of Ichkeria [6, 27, 28]. This feature calls for a comprehensive consideration of such properties as efficiency, accuracy, secrecy.

One more feature is the complex hierarchical structure of RFS, a large amount of data, and their formality. Moreover, the specified structure of RFS may change during the operation, which predetermines an increase in attention to the stability of the functioning of such systems. This feature is inherent in all, without exception, military conflicts of our time. This is most clearly demonstrated in the fighting clashes between federal troops of the Russian Federation and the armed forces of the unrecognized republic of Ichkeria [6].

In addition, the peculiarities of military (combat) activities should include the dispersal of units and an increase in the volume of tasks. This feature was inherent in the activities in Iraq, Afghanistan, ATO in eastern Ukraine [1–7, 24]. This feature predetermines increased attention to the stability of the functioning of both separate units and RFS in general.

Thus, the special features of military (combat) activities that significantly affect the results of a military conflict are a rapid change in the situation; competition with an enemy for winning in time, accuracy, maneuverability, secrecy. In addition, these features include the formalized service information; relatively large amount of data that must be operated when deciding on combat use (hostilities). In addition, the features include the consistency of actions and a clear structure of subordination; relative autonomy in terms of provision and location.

Based on the special features of military (combat) activities, it is possible to identify the criteria that most significantly affect the functioning of RFS using cluster analysis.

The structuring of the above requirements and its further analysis involving the splitting into clusters makes it possible to define the criteria for the selection of RFS taking into consideration the peculiarities of military (combat) activities (Fig. 4).

Thus, the most important selection criteria include efficiency, accuracy, secrecy, stability.

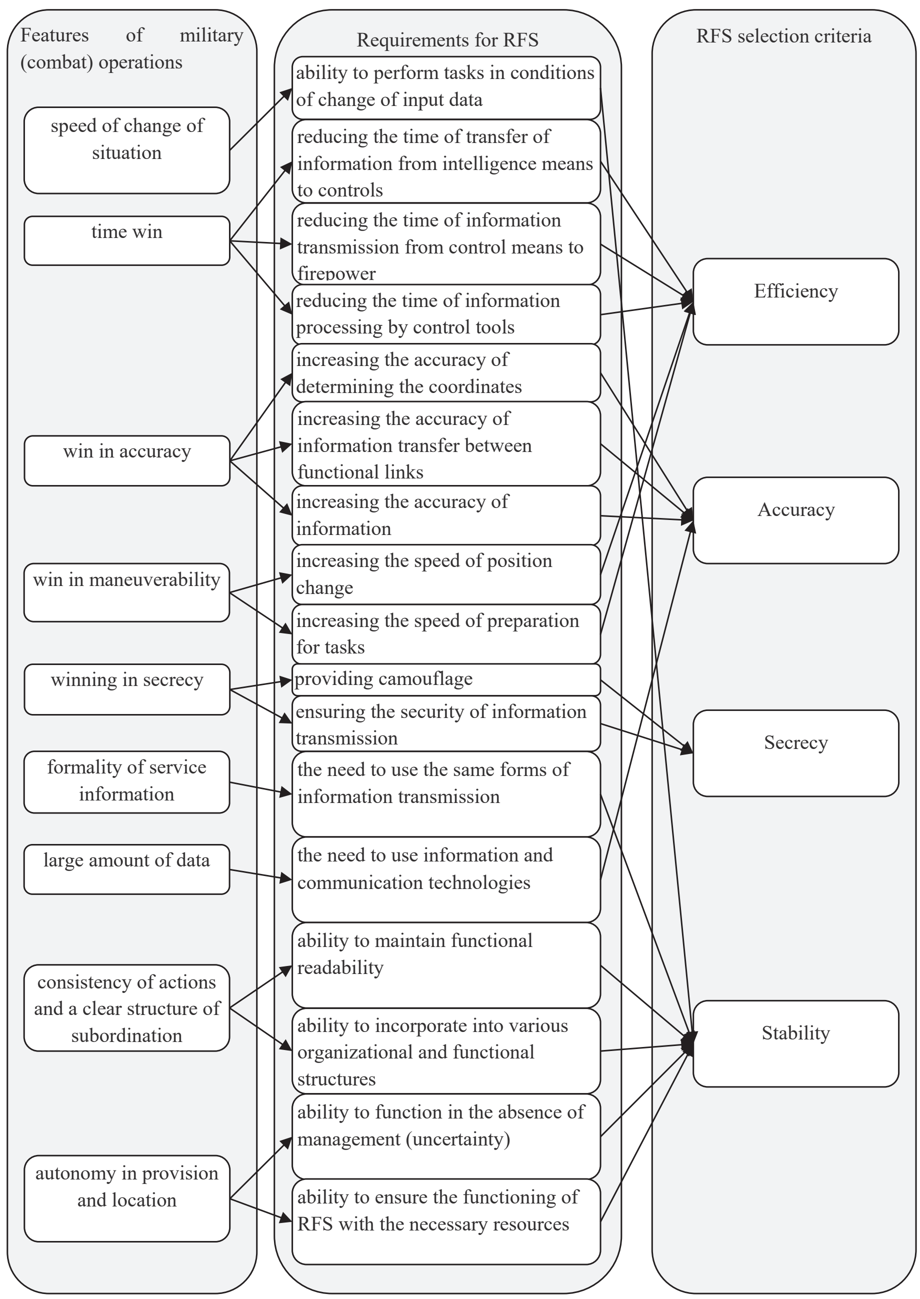

Fig. 4. Scheme of interrelation between the peculiarities of military (combat) activities and the criteria for RFS selection

Moreover, the efficiency in the current study is understood as the ability to implement functions under two conditions, in particular: the ability to implement functions earlier than the enemy and before a task is irrelevant.

In general, «efficiency», as well as other selection criteria, are the properties of RFS. This makes it possible to match the selection criteria with the requirements for RFS stated in the guidelines and methodological documents.

Hereafter, «accuracy» means the ability to implement functions within the established tolerances.

The criterion of «secrecy» is understood as the ability to perform functions without signs that can be detected by the enemy. The criterion of «stability», in this study, is understood as the ability to perform functions under the influence of negative factors.

The next element of the input data is the tactics and technical characteristics of RFS. Several RFS were selected for our calculations, taking into consideration the available information about them and similar characteristics (we selected RFS of type C2-C2SR). Thus, for further calculations, the following RFS were chosen: «Kropyva», «ArtOS», «Obolon-A», «Sokil».

The main purpose of the combat control system of the tactical unit «Kropyva» is the automation of individual control tasks at the level of battalion (division), company (battery), platoon, a separate unit of equipment (gun) [29].

The purpose of the hardware-software complex of the automated fire control unit of the artillery unit «ArtOS» is to manage the artillery units in the link «battery commander – senior battery officer – gun commander – gunner» in an automatic mode [30].

The automated control system «Obolon-A» is designed to control in automated mode the movement of the unit on the march, the deployment of batteries (firearms) from the march to arbitrary firing positions. The division's fire control complex can simultaneously process information about dozens of targets at once, working with its own and added ground and air reconnaissance means, as well as with information from the senior chief [31, 32].

The reconnaissance and strike complex «Sokil» is designed to find and defeat the target, using, depending on the tasks, ammunition of explosive, explosive and thermobaric action [33, 34]. The analysis of data in Table 2 makes it possible to generally assess the advantages and limitations of each RFS in accordance with the selection criteria (efficiency, accuracy, secrecy, stability). However, it is impossible to unequivocally identify the best or worst option. These data are initial for experts in addition to their experience and knowledge, in order to conduct assessments.

The next block of input data concerns experts and their competence. Thus, during the survey, a list of 30 experts was compiled, which ensures the minimum possible level of statistical error (the number of studies (judgments) exceeds 20).

A generalized description of the competence of experts is given in Table 3.

Table 3

Generalized description of experts' competence

Expert No.	Self-estimation $C_{\beta,c}$	Averaged mutual assessment $C_{\beta,a}$	Objective component $C_{\beta,o}$	Coefficient of relative competence of the β-th member of the expert group C_β
1	0.7	0.9	0.8	0.595
2	0.8	0.6	0.7	0.52
3	1	0.9	1	0.95
4	0.5	0.7	0.5	0.3
5	0.6	0.8	0.9	0.51
6	0.8	0.9	1	0.76
7	0.9	0.8	0.9	0.765
8	0.6	0.5	0.8	0.39
9	1	1	1	1
10	0.9	0.9	1	0.855
11	0.7	0.8	0.8	0.56
12	0.9	0.6	0.5	0.495
13	0.6	0.7	0.9	0.48
14	0.6	0.8	0.7	0.45
15	1	0.9	0.8	0.85
16	0.5	0.5	0.5	0.25
17	0.8	0.6	0.9	0.6
18	0.6	0.6	0.7	0.39
19	0.9	0.8	0.7	0.675
20	1	0.7	0.8	0.75
21	1	0.8	1	0.9
22	0.6	0.6	0.5	0.33
23	0.7	0.8	0.9	0.595
24	0.9	0.8	0.9	0.765
25	0.6	0.7	0.6	0.39
26	0.5	0.4	0.7	0.275
27	0.7	0.7	0.8	0.525
28	1	1	1	1
29	0.8	0.9	0.8	0.68
30	1	1	0.7	0.85

Table 2

Tactical-technical characteristics of reconnaissance-firing systems

Characteristic	Reconnaissance-firing system			
	Sokil	Kropyva	Obolon-A	ArtOS
Reconnaissance depth, km	to 50	to 100	to 150	to 100
Range of defeat, km	to 30	to 60	to 120	to 60
Detection-defeat cycle time, min	to 10	to 10	to 15	to 5
Probability of detection (defeat) of system elements in the period of 10 min after the beginning of active functioning	0.5	0.5	0.7	0.3
The standard deviation of the coordinates of detection (defeat) of the target, m	25	10	50	10

5. 3. Analysis of the calculation results for an example of the application of the procedure for justifying the choice of RFS

In accordance with the proposed procedure (Fig. 3), we generalized the judgment of experts taking into consideration their competence in relation to the criteria for choosing RFS; the results are given in Table 4.

The results of the analysis of Table 4 indicate the priority of such a criterion as stability while efficiency has the lowest priority. This fact can be explained by that efficiency generally affects the effectiveness of a particular task, and stability – efficiency during the operation. The consistency ratio does not exceed 10 %, so we applied a pairwise comparison of RFS relative to each of the criteria similar to formulae (2) to (5) illustrated by Tables 5–8.

Our analysis of the results of RFS pairwise comparison relative to the criterion «efficiency» (Table 5) indicates that the best option is the ArtOS RFS. This result can be explained by the fact that the specified RFS works with the Internet; accordingly, it has the highest response speed.

The results of our analysis of the pairwise comparison of RFS relative to the criterion «accuracy» (Table 6) indicate that the worst option is the Kropyva RFS. This is due to the fact that the specified RFS uses interpolated firing tables, which significantly reduces accuracy.

Table 4

Table of pairwise comparison of RFS selection criteria

Criterion	Efficiency	Accuracy	Secrecy	Stability	Eigenvector component estimate	Priority vector normalized estimate
Efficiency	1.0	0.5	0.3	0.3	0.561	0.130
Accuracy	2.0	1.0	0.5	0.5	0.871	0.202
Secrecy	3.0	2.0	1.0	0.5	1.246	0.288
Stability	3.0	2.0	2.0	1.0	1.644	0.380
Total					4.3	1

Note: Consistency index is 0.09. Consistency ratio is 10 %.

Table 5

Table of RFS pairwise comparison relative to the criterion «efficiency»

RFS designation	Sokil	Kropyva	Obolon-A	ArtOS	Eigenvector component estimate	Priority vector normalized estimate
Sokil	1.0	0.5	0.5	0.3	0.537	0.123
Kropyva	2.0	1.0	0.7	0.5	0.904	0.207
Obolon-A	2.0	1.5	1.0	0.7	1.189	0.273
ArtOS	3.0	2.0	1.5	1.0	1.732	0.397
Total					4.4	1

Note: Consistency index is 0.003. Consistency ratio is 0 %.

Table 6

Table of RFS pairwise comparison relative to the criterion «accuracy»

RFS designation	Sokil	Kropyva	Obolon-A	ArtOS	Eigenvector component estimate	Priority vector normalized estimate
Sokil	1.0	2.0	1.4	0.7	1.175	0.269
Kropyva	0.5	1.0	0.5	0.5	0.595	0.136
Obolon-A	0.7	2.0	1.0	0.3	0.827	0.189
ArtOS	1.5	2.0	3.0	1.0	1.732	0.396
Total					4.3	1

Note: Consistency index is 0.02. Consistency ratio is 2 %.

Table 7

Table of RFS pairwise comparison relative to the criterion «secrecy»

RFS designation	Sokil	Kropyva	Obolon-A	ArtOS	Eigenvector component estimate	Priority vector normalized estimate
Sokil	1.0	1.4	2.0	0.3	0.988	0.228
Kropyva	0.7	1.0	1.4	0.5	0.841	0.195
Obolon-A	0.5	0.7	1.0	0.5	0.647	0.149
ArtOS	3.0	2.0	2.0	1.0	1.861	0.428
Total					4.3	1

Note: Consistency index is 0.03. Consistency ratio is 3 %.

Table 8

Table of RFS pairwise comparison relative to the criterion «stability»

RFS designation	Sokil	Kropyva	Obolon-A	ArtOS	Eigenvector component estimate	Priority vector normalized estimate
Sokil	1.0	0.3	0.7	0.3	0.522	0.120
Kropyva	3.0	1.0	1.4	0.7	1.300	0.298
Obolon-A	1.5	0.7	1.0	0.5	0.851	0.195
ArtOS	3.0	1.5	2.0	1.0	1.732	0.397
Total					4,4	1

Note: Consistency index is 0.01. Consistency ratio is 2 %.

Our analysis of the pairwise comparison of RFS relative to the criterion of «secrecy» shows that the best option is the ArtOS RFS while the worst is the Obolon-A RFS. This result is explained by the fact that ArtOS is based on portable mobile devices and can use related information. At the same time, Obolon-A is based on automotive technology, which significantly affects secrecy.

The results of our analysis of the pairwise comparison of RFS relative to the criterion «stability» (Table 8) indicate that the best option is the ArtOS RFS while the worst is the Sokil RFS. This can be explained by the fact that ArtOS uses high-order data encryption, with the ability to work both on a local network and a global one (such as the Internet). At the same time, the stability of the Sokil RFS depends on the stability of UAV, which also acts as both a reconnaissance vehicle and a means of destruction.

Next, data from Tables 4–8 were summarized in Table 9; calculation formula (6) was used to define global priorities regarding RFS relative to each of the criteria.

Table 9

Table for defining the global priority metric for each selection criteria

Alternative	Criterion				Global priority
	efficiency	accuracy	secrecy	stability	
	priority vector numerical value				
	0.130	0.201	0.288	0.380	
Sokil	0.123	0.269	0.226	0.120	0.181
Kropyva	0.207	0.136	0.193	0.298	0.223
Obolon-A	0.273	0.189	0.148	0.195	0.191
ArtOS	0.397	0.397	0.427	0.397	0.406

The results of our analysis of the obtained data show that the hardware and software complex of automated fire control of the artillery unit ArtOS has a significant advantage compared to other similar means, from 17 to 22 % (Fig. 5). Accordingly, the worst version of RFS is Sokil with almost the same result (better by 1 %) demonstrated by the Obolon-A RFS.

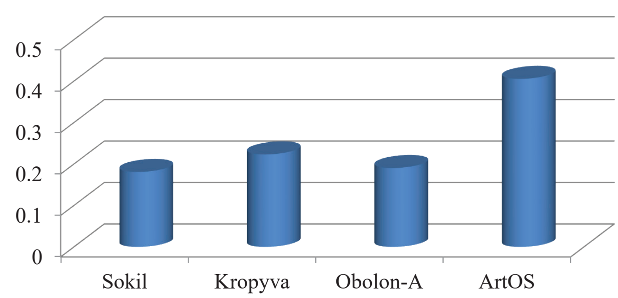

Fig. 5. Results of RFS selection using the proposed procedure

Such results are explained by an integrated approach to taking into consideration the requirements for the design of ArtOS. As for other RFS, it should be noted that despite similar tactics and technical characteristics, each of these RFS has certain shortcomings for at least one of the criteria.

In general, the calculation of the example shows that a given procedure could provide for a reasonable choice of RFS for certain conditions in accordance with reasonable selection criteria.

In addition, this procedure is based on such a combination of the methods of cluster analysis, expert evaluation, and hierarchy analysis, which predetermines a decrease in errors in the results.

6. Discussion of results of devising a procedure for justifying the choice of reconnaissance-firing systems

An algorithm for substantiating the choice of RFS has been proposed that takes into consideration certain conditions (Fig. 3). This algorithm is based on the combination of methods of cluster analysis, expert evaluation, and hierarchy analysis. This combination was applied to eliminate the shortcomings of these methods, in particular, the high computational complexity, uncertainty in the formalization of input data, subjectivism of results.

The high direct computational complexity, which is inherent in the method of hierarchy analysis, was overcome using only one level of hierarchies, which became possible by using cluster analysis to form the input data. Uncertainty in the formalization of input data was overcome by using expert evaluation and the coordination of expert judgments. The subjectivism of the results was overcome using a hierarchy analysis method and the coordination of experts' opinions in accordance with their competence (Table 3).

The advantages of this approach are that combining the methods of expert evaluation and hierarchy analysis produces the coordination of the results twice. Thus, when filling out questionnaires (Fig. 1, 2), the consistency of judgments of one expert is checked, accordingly, the parameters of the consistency index and the ratio of consistency according to estimation dependences (4), (5) are determined. Next, the judgments of all experts are agreed upon, taking into consideration the weight coefficient of each expert. This fact significantly reduces the subjectivism of the results.

Regarding the limitations of the use of the algorithm for justifying the choice of RFS taking into consideration certain conditions (Fig. 3), it should be noted the need to apply it to RFS of one class.

The limitation of this algorithm is the imperfection of the data refinement procedure (Fig. 3, step 12a). At the same time, this may define a further direction of research and improvement of the proposed algorithm (procedure).

We have defined a set of criteria for choosing RFS (Fig. 4), which is based on the cluster analysis of the requirements for RFS predetermined by the peculiarities of modern military (combat) activities. This set makes it possible to reasonably approach the analysis of the tactics and technical characteristics of RFS (Table 2) and the application of evaluation by experts in accordance with their competence (Table 3). It also resolves the issue of the lack of criteria for choosing RFS, which are most important depending on the conditions of military (combat) activities.

The advantages of the obtained set of criteria for choosing RFS include their relation to the requirements predefined by the specified features of modern military (combat) activities (Fig. 4). It should also be noted that this set includes only four elements (Table 4), which greatly simplifies calculations while maintaining the completeness of coverage of the properties of RFS functioning.

Restrictions on the use of this set are the features of military (combat) activities. That is, when changing the features or the emergence of new ones, it is necessary to reconsider the defined totality. It should also be noted that the above set can adequately be applied only to RFS of one class. It should also be noted that in the case when the number of experts is less than 20 the statistical error in operating the specified set of criteria may increase significantly.

The limitation of this set is a certain interdependence of criteria, which somewhat affects the results. In the future, it is proposed to investigate the correlation functions of these criteria and apply them in the procedure.

In addition, a limitation to be considered is a significant amount of work to compile a circle of experts and determine their competence.

The next task of our study was to analyze the results of calculating an example of the application of the procedure for justifying the choice of RFS. The result obtained is the defined quantitative parameter of the advantage of a certain RFS, in particular, the ArtOS RFS, compared to other RFS (Fig. 5, Table 9). This result is based on a combination of the algorithm for justifying the choice of RFS (Fig. 3), a set of criteria for choosing RFS (Fig. 4), and the combination of methods of cluster analysis, expert evaluation, and hierarchy analysis.

In general, our result makes it possible to overcome the problem related to the inability to define the justified advantage of a certain RFS over another.

The advantage of this result is the possibility to quantify the advantage of one RFS relative to another.

The limitation is that this result can be used only for the conditions of modern military (combat) activities with their peculiarities.

Another limitation is that this result does not take into consideration other RFS from other classes. However, this may become the direction of further research.

It is important to realize that the current study is focused on the development of a procedure for justifying the choice of RFS; the calculations were performed to confirm its performance. Although the results of practical calculations give an interesting result, however, the main task is, nevertheless, the development of a scientific and methodological apparatus.

In general, the totality of our results indicates the development of a procedure for justifying the choice of RFS taking into consideration the conditions of military (combat) activities. The procedure includes an algorithm (Fig. 3), input data: selection criteria (Fig. 4), the tactics and technical characteristics of RFS (Table 2), and the competence of experts (Table 3). This technique has been tested for operability by considering an example of choosing RFS (Tables 4–9) leading to an adequate result (Fig. 5), confirmed by the judgments of experts.

In general, such a scientific result makes it possible to overcome the shortcomings that are found both in the practical and theoretical aspects.

Regarding the advantages of our procedure, it is necessary to note its relative simplicity. After all, it can be used without additional formalization for the consumer. In addition, this technique does not require special skills of the researcher for its use. Another advantage of this procedure is its modularity, that is, the ability to replace certain blocks with others, more appropriate for the conditions of a particular operation.

Another advantage is the ability to process data that does not have clearly defined quantitative estimates. These data include the speed of change in the situation; winning in time, maneuverability, secrecy; the formality of service information. In addition, the data that are difficult to describe quantitatively include the consistency of actions and clarity of subordination structure; the relative autonomy in terms of provision and location. That is, these data show signs of fuzziness or discrepancy of indicators but, with the help of our procedure, they can be taken into consideration to obtain a reasonable result.

The advantages also include the direct linking of the criteria for choosing RFS to the peculiarities of military (combat) activities.

Restrictions on the use of this procedure are that at this stage of research only RFS of one class can be evaluated. However, given the modularity of this technique, this can be easily corrected by developing an appropriate scientific and methodological apparatus. Another limitation is the mandatory consideration of the features of exactly the operation where it is planned to use RFS.

In general, regarding the shortcomings of the current study, it should be noted that it is aimed at developing a procedure for choosing RFS, which, in some way, echoes the assessment of the effectiveness of the use of RFS, but this is not the case. It is clear that testing the effectiveness of the use of RFS in particular through the mathematical expectation of the number of hit targets would be appropriate. However, the lack of such a procedure for evaluating the effectiveness of RFS, according to the criteria chosen in this study, makes it impossible. Moreover, taking into consideration the number of targets, their types of means of destruction adds significant uncertainty and requires a separate study of the effectiveness of the use of RFS.

7. Conclusions

1. An algorithm to substantiate the choice of RFS taking into consideration certain conditions has been proposed. Its essence implies the structuring of steps to cluster the input data, to process expert judgments taking into consideration their competence, and to analyze these judgments using a hierarchy analysis method. The special features of this algorithm are the use of a certain amount of input data that have high-quality value and signs of fuzziness. Distinctive features of this algorithm are such a combination of cluster analysis, expert evaluation, and hierarchy analysis methods, which could eliminate the existing shortcomings of these methods. In particular, high computational complexity, uncertainty in the formalization of input data, subjectivism of results. The scope of this algorithm is determined by the method for justifying the choice of RFS, taking into consideration the conditions of military (combat) activities.

2. A set of criteria for choosing RFS has been built. The result implies defining such criteria for the choice (properties of functioning) of RFS, which reflect the ability to perform tasks for its intended purpose. The peculiarity and distinctive feature of this set is that it is based on the cluster analysis of the requirements for RFS predetermined by the peculiarities of modern military (combat) activities. This feature makes it possible to overcome the problem of the absence of such criteria for choosing RFS that are the most important depending on the conditions of military (combat) activities. The area of practical application includes research of issues related to the choice, evaluation of efficiency, design of RFS.

3. A quantitative parameter of the advantage of a certain RFS, in particular, the ArtOS RFS, compared to other RFS, has been determined. This advantage, for the conditions of modern activities, is from 17 to 22 %. The peculiarity and

distinctive feature of this result is its quantitative value. Due to this feature, it was possible to resolve the issue related to the inability to determine the justified advantage of a certain RFS over another. The scope of this result is the practical actions of commanders (chiefs) in planning military (combat) activities.

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