Improvement of the operations planning process using a hybridized fuzzy-multi-criteria decision-making approach

Ivan B. Petrović[a], *Milan* Ž. Milenković[b]

[a] University of Defence in Belgrade, Military Academy,
Belgrade, Republic of Serbia,
e-mail: ivanpetrovic1977@gmail.com, **corresponding author**,
ORCID iD: https://orcid.org/0000-0001-7372-637X

[b] University of Defence in Belgrade, School of National Defence
"Field Marshal Radomir Putnik", Belgrade, Republic of Serbia,
e-mail: micko0307@gmail.com,
ORCID iD: https://orcid.org/0009-0008-9315-3802

https://doi.org/10.5937/vojtehg72-51473

FIELD: applied mathematics, military sciences
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: The possibility of optimizing decision making in the operations planning process in air defence units by applying a multi-criteria decision-making approach in a fuzzy environment is shown in the paper. By analyzing the content of the available literature, the selection criteria were determined based on which it is possible to evaluate and compare the courses of action of air defence units. The criteria are based on the evaluation parameters of the courses of action from the decision matrix in the phase of the operations planning process called the courses of action validation and comparison.

Methods: The proposed approach combines the Laboratory for Testing and Evaluation of Decision Making (DEMATEL) and the Compressed Proportional Assessment (COPRAS) which have been successfully modified by fuzzy triangular sets. The fuzzy-DEMATEL method was applied to determine the criteria's weights, and the fuzzy-COPRAS method was applied to evaluate the alternatives - courses of action.

Results: Multiple fuzzy-multi-criteria decision-making methods were integrated into a unique model that can be applied in the operations planning process with the aim of optimizing the decision-making process.

Conclusion: The paper contributes to military science in making decisions related to the operations planning process at the tactical level in air defence units.

Keywords: Multi-Criteria Decision-Making (MCDM), DEMATEL, COPRAS, Triangular Fuzzy Sets, Operations Planning Process.

ACKNOWLEDGMENT: This paper was written as a part of the scientific research project funded by the Ministry of Defence, Republic of Serbia: VA-DH/1/22-24 "Model upravljanja razvojem sposobnosti sistema odbrane" ("Defence system capability development management model").

Introduction

Making the decision for the use of the air defence missile battalion in the operations planning process is a train of thought established by the coordinating officer based on the decision of the commander in order to logically analyze significant information during the work of the command. It is implemented through a procedure that allows the commander to control the operational planning process. This process globally has variable dynamics, depending on the scenario, that is, the decision-making environment.

The sequence of planning activities is a series of logical, sequential, and analytical processes to: examine a mission; develop, analyze, and compare the courses of action, selecting the best course of action; and produce a plan or order during a military operation (in this case an air defence operation).

The operations planning process in the air defence missile battalion is realized through six phases: initiation, mission analysis, courses of action development, courses of action validation and comparison, commander’s courses of action decision, and plan development. The operations planning process in the air defence missile battalion is regulated by a special instruction that is harmonized with the Guide for Operational Planning of the Armed Forces Commands (Canadian Army Command and Staff College, 2018).

In the air defence missile battalion, the operations planning process takes place through the decision-making process implemented by the operations planning group.

The operations planning group is formed by members of the battalion command. If necessary, subordinate commanders as well as members of superior command (air defence missile brigade) are involved in the operations planning process.

The composition of the operations planning group is defined by the Standard Procedure for Operations Planning Process, which is developed by each air defence missile battalion command at its own level, in accordance with the Guide for Operational Planning of the Armed Forces Commands (UK Ministry of Defence, 2019). The operations planning group of the air defence missile battalion has seven members of command, while in the expanded composition this group can have up to twelve members.

The fourth phase of the decision-making process, the courses of action validation and comparison, begins with an ongoing analysis that evaluates the advantages and disadvantages of all courses of action. Each member of the operations planning group presents their conclusions for further consideration. Using previously developed commander's selection criteria, the operations planning group analyzes each course of action. By comparing the courses of action, their advantages and disadvantages are identified in relation to each other, in order to finally identify the one with the highest probability of success, in relation to the most likely and most dangerous enemy's courses of action.

One of the problems in the work of the operations planning group is that, in the process of selecting group members, no expertise process was carried out, but the composition of the operations planning group was determined based on the duties of the members of the air defence missile battalion command. Bearing this in mind, the subjectivity of the operations planning group members can significantly influence the decision-making process.

The paper considers the optimization and improvement of the operations planning process by applying appropriate objective tools in the decision-making approach, in this case the methods of multi-criteria decision-making.

Namely, on the basis of adequate input values, multi-criteria decision-making methods provide a quick optimal output - response, based on modern computer technologies and soft computing and which can be applied in the decision-making process in the operations planning process in the air defence missile battalion. The application of these methods enables the optimization of the process in an objective way; based on the subjective judgment of the respondents (those methods are subjectively oriented programming methods in soft computing). The possibility of improving the operations planning process was considered in accordance with the principle of limitations, that is, it was examined only in the phase of the courses of action validation and comparison. The object of the application of multi-criteria decision-making methods is the decision-making matrix, which is used in the phase of the courses of action validation and comparison to select the best alternative - course of action from the offered courses of action. In the paper, MCDM methods were first applied for the prioritization of the criteria, and then for the evaluation of the courses of action. There are two types of MCDM methods used in scientific research. The first type is represented by multiple attribute decision making (MADM) methods, while the second type is represented by multiple objective decision making (MODM) methods. MADM involves the selection of the "best" alternative from pre-specified alternatives described in terms of multiple attributes (Zavadskas et al, 2014; Sabaei et al, 2015). These methods enable the prioritization of a discrete - finite number of criteria, sub-criteria and attributes in hierarchically structured qualitative - quantitative ambiguous (imperfect) problems. The second category, MODM, involves the design of alternatives which optimize the multiple objectives of the decision maker (Zavadskas et al, 2014; Sabaei et al, 2015). Bearing in mind that the main goal of the paper is to objectively solve the problem of selecting the optimal course of action based on the final number of offered courses of action, as well as that the evaluation of the courses of action is also performed on the basis of a finite number of criteria, the MCDM methods that belong to the category of MADM methods, are applied in the paper. Furthermore, the application of MADM methods is based on the fact that the decision made is the product of the thought process of the members of the operations planning group, which ensures the validity of the application of these operational research methods. Therefore, the application of the MADM method provides a solution to the structural problem of selecting the optimal alternative (course of action) from the finite number of alternatives by ranking them based on the subjective opinion of decision makers (the operations planning group). The decision makers subjectively ranked the alternatives for each of the final number of criteria (with which they previously determined the weights) using linguistic variables, which required the application of fuzzy sets, instead of "crisp" values. Bearing in mind that fuzzy sets provide a suitable mathematical apparatus for solving problems based on uncertainty, ambiguity, subjectivity and indeterminacy, their application was necessary in solving this research problem in the paper. Namely, the criteria, which were used in the decision matrix, are of an undetermined type (they cannot be determined exactly mathematically) that depend on many factors (space, weather conditions, enemies, etc.) and the decision makers made a subjective assessment of their values, which conditioned the application of fuzzy sets. The evaluation of the courses of action is also based on subjectivity and uncertainty, which caused the application of fuzzy sets. Bearing in mind that, in type-1 fuzzy sets, each element has a degree of membership which is described with a membership function valued in the interval between 0 and 1, as well as linguistic variables (intended for decision makers to assess the mutual influence of criteria and evaluate the criteria for each alternative) are unambiguous, type-1 fuzzy sets in the form of triangular fuzzy sets were applied in the paper.

In addition to the introduction and conclusion, the paper consists of three more sections. In the first section, the review of literature was done. In the second section, the methodological basis used in the paper is explained, while in the third section, the results of the research are presented an explained.

Analysis of literature

Multi-criteria decision-making methods are included in operational research methods. The application of these methods for military purposes has been known since their inception. Namely, with the objective of optimizing the radar network, during the Second World War, the British armed forces optimized radar positions by applying operational research methods. After the Second World War, these methods were further enhanced, and they found a very significant application in the Yugoslav Army (the Laboratory for Operational Research at the Faculty of Organizational Sciences in Belgrade is named after Jovan Petrić, colonel of the Yugoslav Army) because their basic purpose was related to the optimization of decision-making processes in organizational systems (the army and its units essentially represent organizational systems). Multi-criteria decision-making methods were developed later, and experienced complete affirmation with the development of computer technologies. There are numerous papers dealing with the application of multi-criteria decision-making methods for military purposes. For example, Inđić et al. (2018) dealt with the selection of unmanned aerial vehicles for the needs of chemical accident area reconnaissance, for the purposes of chemical recognition. Božanić et al. (2016) investigated the possibility of applying multi-criteria optimization methods in the operations planning process in the defense operation. The possibility of optimizing military decision-making by applying the FUCOM–EWAA–COPRAS-G MCDM model was researched by Tešić & Božanić (2023). Most of the mentioned papers are in the process of finding practical application in the realization of combat tasks.

Bearing in mind the aforementioned, it can be concluded that there is no single theoretical fund that refers to the application of multi-criteria decision-making methods in the operations planning process in order to select the optimal course of action of a military unit.

Methodological background

For the purposes of this research, the hybridized DEMATEL-COPRAS approach of multi-criteria decision-making on triangular fuzzy sets was applied.

A small number of respondents within the operations planning process in the air defence missile battalion results in the application of fuzzy sets. Namely, as mentioned earlier in the paper, in contrast to "crisp" values, which give representative results on a large sample, in the case of a small sample, as is the case in this paper, the representativeness and reliability of the results is obtained by applying triangular fuzzy sets (the application of this type of numbers is related to decision making in the conditions of uncertainty and subjectivity of experts' opinion).

The triangular fuzzy set $\tilde{A}$ for each number a is $\mu(a)$, where $\mu(a)$ is a membership function a of the triangular fuzzy set $\tilde{A}$ in the interval $[0,1]$ for two triangular fuzzy sets:

$$\tilde{A}_1 = (l_1, m_1, u_1) \text{ and}$$

$$\tilde{A}_2 = (l_2, m_2, u_2).$$

The elementary operations necessary for the application of multi-criteria decision-making methods on the aforementioned triangular fuzzy sets are as follows (Chang, 1996; Kahraman et al, 2014; Petrović & Petrović, 2021):

$$\tilde{A}_1 + \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{1}$$

$$\tilde{A}_1 - \tilde{A}_2 = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \tag{2}$$

$$\tilde{A}_1 \times \tilde{A}_2 = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \tag{3}$$

$$\tilde{A}_1 \div \tilde{A}_2 = (l_1 \div u_2, m_1 \div m_2, u_1 \div l_2) \tag{4}$$

$$k \times \tilde{A}_i = (k \times l_i, k \times m_i, k \times u_i) \tag{5}$$

$$\frac{\tilde{A}_i}{k} = \left(\frac{l_i}{k}, \frac{m_i}{k}, \frac{u_i}{k}\right) \tag{6}$$

where k is a scalar ("crisp value") – a real number

$$\frac{1}{\tilde{A}_i} = \left(\frac{1}{u_i}, \frac{1}{m_i}, \frac{1}{l_i}\right) \tag{7}$$

$$\sqrt[m]{\tilde{A}_i} = \left(\sqrt[m]{l_i}, \sqrt[m]{m_i}, \sqrt[m]{u_i}\right) \tag{8}$$

Defuzzification of the triangular fuzzy sets is done by using the following formula (Kahraman et al, 2014; Petrović & Petrović, 2021):

$$a_i = \frac{l_i + 4 \times m_i + u_i}{6}. \qquad (9)$$

There are a number of MCDM methods that can be used to prioritize criteria in a structured model: FUCOM (Full Consistency Method), LBWA (Level Based Weight Assessment), OPA (Ordinal Priority Approach), etc. The FUCOM algorithm is based on the pairwise comparisons of criteria, where only the n − 1 comparison in the model is necessary. One of the characteristics of the developed new method is the lowering of decision-maker's subjectivity, which leads to consistency or symmetry in the weight values of the criteria (Khan et al, 2022; Tešić & Božanić, 2023). The LBWA method enables the involvement of experts from different fields with the purpose of defining the relations between criteria and providing rational decision making. The LBWA model has several key advantages: (1) the LBWA model allows the calculation of weight coefficients with a small number of criteria comparisons, only n-1 comparison; (2) the algorithm of the LBWA model does not become more complex with the increase of the number of criteria, which makes it suitable for use in complex MCDM models with a large number of criteria; (3) by applying the LBWA model, optimal values of weight coefficients are obtained with a simple mathematical apparatus that eliminates inconsistencies in expert preferences, which are tolerated in certain subjective models (Žižović & Pamučar, 2019). An advantage of the OPA method is that it does not make use of the pairwise comparison matrix, the decision-making matrix (no need for a numerical input), normalization methods, averaging methods for aggregating the opinions of experts (in GDM), and linguistic variables. Another advantage of the OPA method is the possibility for experts to only comment on the attributes and alternatives for which they have sufficient knowledge and experience (Ataei et al, 2020).

The validation of the selection criteria was carried out by using the fuzzy-DEMATEL (Decision – Making Trialand Evaluation Laboratory) method. This method is based on the determination of direct and indirect influences between each criterion on each criterion (Kahraman et al, 2014; Petrović & Petrović, 2021). It was developed with the aim of studying groups with complex and connected relationships. This method was chosen for the prioritization of criteria because it analyzes structures with complex causal relationships between their elements in partially determined or non-deterministic organizational systems and processes. Namely, as already mentioned, the criteria used in the paper are partially deterministic or non-deterministic. They are partially determined through the components of the operational environment such as one's own military forces, a physical combat component (qualitative-quantitative properties of land and relief), and a weather component (complex meteorological conditions). However, these criteria also depend on the enemy's forces and their ability to reduce the values of the courses of action for all criteria, which makes the criteria both non-deterministic and partially disordered. Also, the advantage of the DEMATEL method is that it enables the identification and elimination of less important criteria during the detailed analytical process of determining a large number of criteria for evaluating the courses of action.

The degree of direct and indirect influences (no influence, low, medium, high or very high influence) between each criterion on all other criteria was gathered by all members of the operations planning group, individually, by using the DEMATEL questionnaire. Based on this data, the initial matrix of influence was formed for each member of the operations planning group. The element values per row represent the degree of influence that each criterion has on other criteria (direct influence), and the element values per column represent the influence that other criteria have on each criterion (indirect influence). These matrices provided the application of the fuzzy-DEMATEL method.

The procedure of the fuzzy-DEMATEL method is done as follows (Kahraman et al, 2014; Petrović & Petrović, 2021):

The first step: The initial average fuzzy set matrix of the influence between the criteria is obtained by aggregating the individual (initial) fuzzy set of influence (after the transformation of the linguistic variables in the triangular fuzzy sets values) for each ij - element of $\tilde{A} = \left[\tilde{a}_{ij} \right]_{n\times n}$:

$$\tilde{A} = \left[\tilde{a}_{ij} \right]_{n\times n} = \left[\frac{\tilde{a}_{ij}^{(1)} \oplus \tilde{a}_{ij}^{(2)} \oplus \ldots \oplus \tilde{a}_{ij}^{(k)}}{k} \right]_{n\times n} \tag{10}$$

where $\tilde{a}_{ij} = \left(l_{ij}, m_{ij}, u_{ij} \right)$ is the triangular fuzzy set element of the non-negative matrix ($1 \le i \le n$ -number of columns, $1 \le j \le n$ - number of rows in the initial average fuzzy matrix of the influence).

k - the number of members of the operations planning group (decision makers).

The second step: The normalized direct-relation matrix is:

$$\tilde{X} = \left[\tilde{x}_{ij} \right] = s \times \tilde{A} \tag{11}$$

where $s = 1 / \max_{1 \le i \le n} \sum_{j=1}^{n} u_{ij}$.

The third step: The total relation matrix is:

$$\begin{aligned}
&\tilde{T} = \left[\tilde{t}_{ij} \right]_{n \times n}, \tilde{t}_{ij} = \left(l_{ij}^{t}, m_{ij}^{t}, u_{ij}^{t} \right), \\
&l_{ij}^{t} = l_{ij}^{x} \times \left(l_{ij}^{i} - l_{ij}^{x} \right)^{-1}, \\
&m_{ij}^{t} = m_{ij}^{x} \times \left(m_{ij}^{i} - m_{ij}^{x} \right)^{-1}, \\
&u_{ij}^{t} = u_{ij}^{x} \times \left(u_{ij}^{i} - u_{ij}^{x} \right)^{-1}, i, j = 1, 2, \ldots, n
\end{aligned} \tag{12}$$

$\tilde{I} = \left[\tilde{i}_{ij} \right]_{n \times n}, \tilde{i}_{ij} = \left(l_{ij}^{i}, m_{ij}^{i}, u_{ij}^{i} \right), i, j = 1, 2, \ldots, n$ is the triangular fuzzy set identity square matrix with the values on the main diagonal: $\tilde{i}_{ij} = (1,1,1)$, $1 \le i \le n, 1 \le j \le n, i = j$,

Other values of the triangular fuzzy set identity square are: $\tilde{i}_{ij} = (0,0,0)$, $1 \le i \le n, 1 \le j \le n, i \ne j$

The fourth step: After defuzzification of the triangular fuzzy total relation matrix elements $T_{ij}^{def} = \left[t_{ij}^{def} \right]_{n \times n}$ (using formula 9), the sum of the rows $D_i, i = 1,2,\ldots, n$ and the sum of the columns $R_j, j = 1,2,\ldots, n$ of the defuzzificated total relation matrix T_{ij}^{def} is calculated using the following formulas (Baykasoğlu & Gölcük, 2017; Kahraman et al, 2014; Petrović & Petrović, 2021):

$$D_i = \sum_{j=1}^{n} t_{ij}^{def} \tag{13}$$

$$R_j = \sum_{i=1}^{n} t_{ij}^{def} \tag{14}$$

The fifth step: The weights of the criteria are (Baykasoğlu & Gölcük, 2017):

$$w_i = \sqrt{(D_i + R_i)^2 + (D_i - R_i)^2} \quad . \tag{15}$$

The sixth step: The normalized criteria’s weights are:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}, \; i = 1,..., \; n \text{ - the number of the criteria} \quad . \tag{16}$$

As in the case of the prioritization criteria, there are numerous methods that can be used to evaluate alternatives (MABAC, VIKOR, MARCOS, COPRAS, etc.). The Multi-Attributive Border Approximation area Comparison (MABAC) method was introduced by Pamučar & Ćirović (2015). The basic assumption in this method is to define the distance of the alternatives from the border approximation area. The basic adventage of the MABAC method is that this method is a simple but stable mathematical tool that can be integrated with other methods, and the potential values of gains and losses are taken into consideration so that the final result can be comprehensive (Yu et al, 2017). The ViseKriterijumska Optimizacija i Kompromisno Resenje (VIKOR) method was developed by Opricovic (Opricovic & Tzeng, 2004) as an MCDM method to solve a discrete multi criteria problem with noncommensurable and conflicting criteria (Gul et al, 2016; Opricovic & Tzeng, 2004). It is aimed to determine a compromise solution for ranking and selecting considering conflicting criteria. The compromise solution is a feasible solution which is the closest to the ideal solution (Gul et al, 2016; Opricovic & Tzeng, 2004). The advantage of this method is that it calculates the ratio of positive and negative ideal solutions. The Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) method was introduced by Stević et al. (2020). The advantages of this method are: the consideration of an anti-ideal and ideal solution at the very beginning of the formation of an initial matrix, closer determination of the utility degree in relation to both solutions, the proposal of a new way to determine utility functions and their aggregation, the possibility to consider a large set of criteria and alternatives while maintaining the stability of the method (Stević et al, 2020).

In addition to the listed methods, after the prioritization of the criteria in the decision matrix was completed, the selection of the optimal alternative (course of action) was done by using the COPRAS (COPRAS - Compressed Proportional Assessment) method on triangular fuzzy sets. This method is used to assess the maximizing and minimizing index values and the effect of maximizing and minimizing indexes of attributes on the results assessment is considered separately (Alinezhad et al, 2019). The COPRAS method determines a solution with the ratio to the ideal solution and the ratio with the ideal-worst solution (Zavadskas et al, 2008). The feature of the COPRAS method, that it is applied when solving problems in risk management, made it suitable for application in this paper. Other features of this method, which ensure its application in this paper, are: the COPRAS is a compensatory method, criteria and alternatives are independent and the qualitative attributes are converted into the quantitative attributes (Alinezhad et al, 2019). Compensatory of this method and the independence of criteria and alternatives ensures an independent assessment of each member of the operations planning group from the influence of the commander or deputy commander of the unit whose formal influence in the military organization is most often decisive in the decision-making process. Also, all the values of the criteria for evaluating the courses of action are of a qualitative type, which makes this method suitable for application in this paper.

The procedure of the fuzzy-COPRAS method is done as follows (Ghorabaee et al, 2014; Tešić & Božanić, 2023):

The first step: The average fuzzy decision matrix is obtained by aggregating the individual fuzzy decision matrix (after the transformation of the linguistic variables in triangular fuzzy sets values) from the alternative values per criteria for each ij - element of $\tilde{F}$ (Ghorabaee et al, 2014):

$$\tilde{F} = \left[\tilde{f}_{ij}\right]_{n\times n} = \left[\frac{\tilde{f}_{ij}^{(1)} \oplus \tilde{f}_{ij}^{(2)} \oplus \ldots \oplus \tilde{f}_{ij}^{(k)}}{k}\right]_{n\times m}, 1 \le i \le n, 1 \le j \le m \qquad (17)$$

where $\tilde{f}_{ij} = \left(l_{ij}^{f}, m_{ij}^{f}, u_{ij}^{f}\right)$ is

the fuzzy element of the decision matrix,

n - the number of the criteria,

m - the number of the alternative (courses of action), and

k - the number of members of the operations planning group (decision makers).

The second step: The calculation of the normalized fuzzy decision matrix:

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{n\times m} = \left[\tilde{f}_{ij} / \sum_{j=1}^{m} \tilde{f}_{ij}\right], 1 \le i \le n, 1 \le j \le m \qquad (18)$$

where $\tilde{r}_{ij}=\left(l_{ij}^{r},m_{ij}^{r},u_{ij}^{r}\right)$ is

the fuzzy element of the normalized decision matrix.

The third step: The calculation of the weighted normalized fuzzy decision matrix (Ghorabaee et al, 2014; Tešić & Božanić, 2023):

$$\tilde{Z}=\left[\tilde{z}_{ij}\right]_{n\times m}=\left[W_{i}\otimes\tilde{r}_{ij}\right]_{n\times m} \tag{19}$$

where $\tilde{z}_{ij}=\left(l_{ij}^{z},m_{ij}^{z},u_{ij}^{z}\right)$ is

the fuzzy element of the weighted normalized decision matrix.

The fourth step: Summarizing the values of the weighted normalized decision matrix by the benefit criteria $\tilde{P}_{j}$ (criteria that are maximized) and by the cost criteria $\tilde{S}_{j}$ (criteria that are minimized) (Ghorabaee et al, 2014):

$$\tilde{P}_{j}=\sum_{i=1}^{p}\tilde{z}_{ij}^{+},i^{+}\in G^{+},G^{+}=\left\{\tilde{z}_{1j}^{+},\tilde{z}_{2j}^{+},...,\tilde{z}_{pj}^{+}\right\},G^{+}\text{ - the set of benefit criteria }\tilde{z}_{ij}^{+},i=1,...,p \tag{20}$$

$$\tilde{S}_{j}=\sum_{i=1}^{s}\tilde{z}_{ij}^{-},i^{-}\in G^{-},G^{-}=\left\{\tilde{z}_{1j}^{-},\tilde{z}_{2j}^{-},...,\tilde{z}_{sj}^{-}\right\},G^{-}\text{ - the set of cost criteria }\tilde{z}_{ij}^{-},i=1,...,s \tag{21}$$

$p+s=n$, the set of benefit and cost criteria.

The fifth step: After the defuzzification of the sums $\tilde{P}_{j}$ and $\tilde{S}_{j}$ (using formula 9), the values of the relative importance of each alternative for the benefit criteria P_{j} and for the cost criteria S_{j} are obtained. In the next step, the importance of each alternative from the total number of alternatives is determined:

$$Q_{j}=P_{j}+\frac{\sum_{j=1}^{m}S_{j}}{S_{j}\times\sum_{j=1}^{m}\frac{1}{S_{j}}} \tag{22}$$

Finally, the alternatives are ranked. The optimal alternative is the one that has the largest value of Q_{j} (Ghorabaee et al, 2014).

Results and the discussion

In the first step of applying the fuzzy multi-criteria decision-making approach, the criteria of the decision-making matrix that can be used in the phase of the operations planning process courses of action validation and comparison were determined. Based on the literature analysis, the following criteria were determined: ability to command (C1), fire ability (C2), maneuver ability (C3), spatial ability (C4), logistical support (C5), and force protection (C6).

In the next step, five members of the operations planning group evaluated the mutual influence of the criteria using a questionnaire with linguistic variablesand adequate triangular sets shown in Table 1 and in Figure 1.

Table 1 - DEMATEL Causal influence linguistic variables and the triangular fuzzy set values

Causal influence linguistic variables	Triangular fuzzy set values
No influence (N)	(0,0,0)
Low influence (L)	(0,0.25,0.5)
Medium influence (M)	(0.25,0.5,0.75)
High influence (H)	(0,5,0.75,1)
Very high influence (VH)	(0.75,1,1)

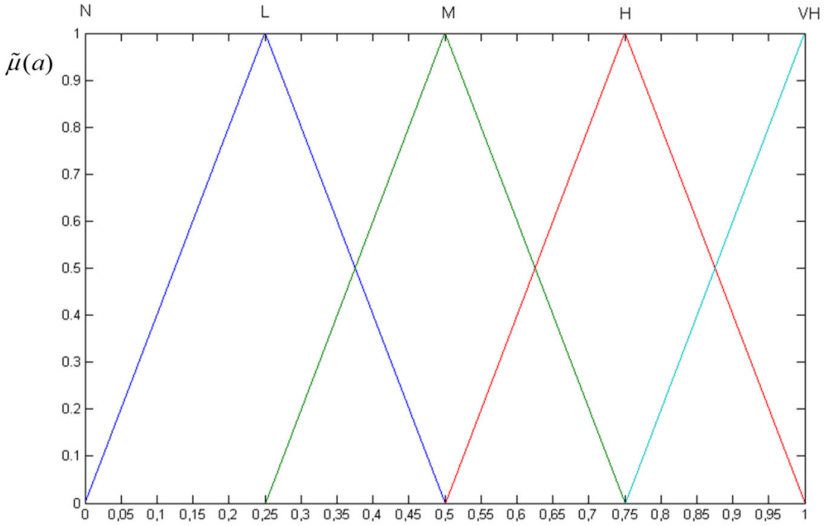

Figure 1 – Triangular fuzzy set for the linguistic variables of influence

The obtained results in the form of the linguistic variables are shown in Table 2.

Table 2 – Answers of the members of the operations planning group in the linguistic variables - matrix of mutual influence

C	C1	C2	C3	C4	C5	C6
C1	N	M+4S	S+4M	4M+H	4S+M	S+M+3H
C2	3S+2H	N	S+4M	5M	5S	3M+2H
C3	VH+3H+M	3S+2M	N	2M+3H	5M	M+3H+VH
C4	M+2VH+2H	5H	M+4H	N	4S+M	M+4H
C5	3M+2H	2S+2M+H	3S+2M	5S	N	4M+H
C6	3H+2VH	2M+2H+VH	5H	5VH	2M+3H	N

After the transformation of the linguistic variables into the triangular fuzzy sets (in accordance with Table 1) was completed, the average fuzzy set matrix of the influence was calculated using formula 10. The obtained results are shown in Table 3.

Table 3 – The average fuzzy set matrix of the influence

C	C1	C2	C3
C1	0,0,0	0.05,0.3,0.55	0.2,0.45,0.7
C2	0.2,0.45,0.7	0,0,0	0.2,0.45,0.7
C3	0.5,0.75,0.95	0.1,0.35,0.6	0,0,0
C4	0.55,0.8,0.95	0.5,0.75,1	0.45,0.7,0.95
C5	0.35,0.6,0.85	0.2,0.45,0.7	0.1,0.35,0.6
C6	0.6,0.85,1	0.4,0.65,0.85	0.5,0.75,1
C	C4	C5	C6
C1	0.3,0.55,0.8	0.05,0.3,0.55	0.35,0.6,0.85
C2	0.25,0.5,0.75	0,0.25,0.5	0.35,0.6,0.85
C3	0.4,0.65,0.9	0.25,0.5,0.75	0.5,0.75,0.95
C4	0,0,0	0.05,0.3,0.55	0.45,0.7,0.95
C5	0,0.25,0.5	0,0,0	0.3,0.55,0.8
C6	0.75,1,1.05	0.4,0.65,0.9	0,0,0

In the next step, formula 11 was used to calculate the normalized direct-relation matrix, and formula 12 was used to calculate the total relation matrix, respectively. The obtained results are shown in Tables 4 and 5.

Table 4 – The average normalized direct-relation matrix

C	C1	C2	C3	C4	C5	C6
C1	0.00,0.00,0.00	0.01,0.06,0.11	0.04,0.09,0.15	0.06,0.11,0.17	0.01,0.06,0.11	0.07,0.13,0.18
C2	0.04,0.09,0.15	0.00,0.00,0.00	0.04,0.09,0.15	0.05,0.10,0.16	0.00,0.05,0.10	0.07,0.13,0.18
C3	0.10,0.16,0.20	0.02,0.07,0.13	0.00,0.00,0.00	0.08,0.14,0.19,	0.05,0.10,0.16	0.10,0.16,0.20
C4	0.11,0.17,0.20	0.10,0.16,0.21	0.09,0.15,0.20	0.00,0.00,0.00	0.01,0.06,0.11	0.09,0.15,0.20
C5	0.07,0.13,0.18	0.04,0.09,0.15	0.02,0.07,0.13	0.00,0.05,0.10	0.00,0.00,0.00	0.06,0.11,0.17
C6	0.13,0.18,0.21	0.08,0.14,0.18	0.10,0.16,0.21	0.16,0.21,0.22	0.08,0.14,0.19	0.00,0.00,0.00

Table 5 – The total relation matrix

C	C1	C2	C3	C4	C5	C6
C1	0.00,0.00,0.00	0.00,0.06,0.08	0.00,0.09,0.11	0.01,0.11,0.13	0.00,0.06,0.07	0.01,0.13,0.15
C2	0.00,0.09,0.12	0.00,0.00,0.00	0.00,0.09,0.11	0.00,0.10,0.12	0.00,0.05,0.06	0.01,0.13,0.15
C3	0.02,0.16,0.19	0.00,0.07,0.10	0.00,0.00,0.00	0.01,0.14,0.17	0.00,0.10,0.12	0.01,0.16,0.19
C4	0.02,0.17,0.20	0.01,0.16,0.18	0.01,0.15,0.18	0.00,0.00,0.00	0.00,0.06,0.08	0.01,0.15,0.20
C5	0.01,0.13,0.15	0.00,0.09,0.10	0.00,0.07,0.09	0.00,0.05,0.07	0.00,0.00,0.00	0.00,0.11,0.13
C6	0.02,0.18,0.22	0.01,0.14,0.16	0.01,0.16,0.21	0.03,0.21,0.22	0.01,0.14,0.16	0.00,0.00,0.00

In the next step, the defuzzificated total relation matrix was obtained using formula 9, and formulas 13 and 14 were used to calculate the sum values of rows and columns. In the last step, the criteria's weights were calculated and their normalization was done using formulas 15 and 16. The obtained results are shown in Table 6 and Figure 2.

Table 6 – Defuzzificated total relation matrix and criteria's weights

C	C1	C2	C3	C4	C5	C6	D_i	R_j	w_i	W_i
C1	0.000	0.020	0.032	0.041	0.018	0.046	0.157	0.313	0.496	0.176
C2	0.035	0.000	0.032	0.037	0.016	0.047	0.166	0.195	0.363	0.129
C3	0.069	0.027	0.000	0.056	0.035	0.067	0.254	0.220	0.475	0.169
C4	0.075	0.063	0.061	0.000	0.022	0.066	0.287	0.248	0.537	0.191
C5	0.046	0.029	0.024	0.019	0.000	0.041	0.159	0.142	0.302	0.108
C6	0.088	0.056	0.071	0.096	0.052	0.000	0.362	0.267	0.636	0.227

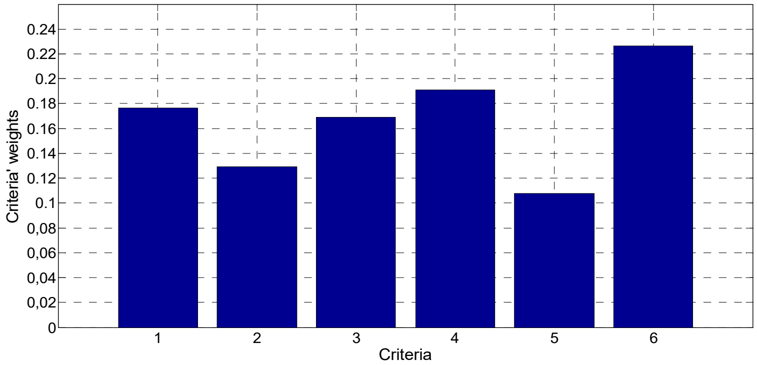

Figure 2 – Criteria's weights of the decision-making matrix

After the prioritization of the selection criteria was completed, using the fuzzy-COPRAS method, the evaluation of alternatives (courses of action of the air defence missile battalion) was carried out. In this case, three courses of action of the air defence missile battalion are proposed. The members of the operations planning group evaluated the alternatives according to the selection criteria. The evaluation was carried out using the answers with the linguistic variables (based on the Likert scale values) shown in Table 7 and in Figure 3.

Table 7 – COPRAS-Likert scale (linguistic variables and triangular fuzzy sets values)

The selection criteria's quality	Likert scale value	Fuzzy sets
Very bad (VB)	1	(0,0,0)
Bad (B)	2	(0,0.25,0.5)
Good (G)	3	(0.25,0.5,0.75)
Very good (VG)	4	(0,5,0.75,1)
Excellent(E)	5	(0.75,1,1)

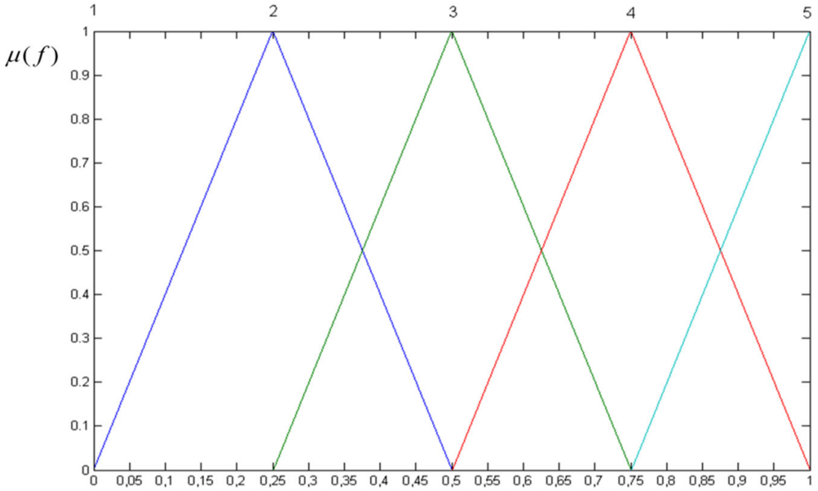

Figure 3 – Triangular fuzzy set for the numerical values of the Likert scale

After the transformation of the values of the linguistic variables into the fuzzy triangular sets, the formation of the average fuzzy decision matrix was done using formula 17. The obtained results are shown in Table 8.

Table 8 – COPRAS linguistic and fuzzy decision matrix

$\tilde{F}$	COA1		COA2		COA3	
C1	3VG+2G	0.4,0.65,0.9	2G+2VG+E	0.45,0.7,0.9	VG+4E	0.7,0.95,1
C2	4G+VG	0.3,0.55,0.8	G+4E	0.65,0.9,0.95	4VG+E	0.55,0.8,1
C3	G+VG+3E	0.6,0.85,0.95	2G+3VG	0.4,0.65,0.9	3VG+2E	0.6,0.85,1
C4	G+2VG+2E	0.55,0.8,0.95	2G+2VG+E	0.45,0.7,0.9	2VG+3E	0.65,0.9,1
C5	G+VG+3E	0.6,0.85,0.95	4VG+E	0.55,0.8,1	2G+3VG	0.4,0.65,0.9
C6	2L+G+2VG	0.25,0.5,0.75	G+3VG+E	0.5,0.75,0.95	2VG+3E	0.65,0.9,1

Using formula 18, the normalized decision matrix was calculated. The obtained results are shown in Table 9.

Table 9 – COPRAS normalized fuzzy decision matrix

$\tilde{R}$	W_i	COA1	COA2	COA3	$\sum_{j=1}^{m}\tilde{f}_{ij}$
C1	0.176	0.143,0.283,0.581	0.161,0.304,0.581	0.161,0.413,0.645	1.55,2.3,2.8
C2	0.129	0.109,0.244,0.533	0.236,0.400,0.633	0.236,0.356,0.667	1.5,2.25,2.75
C3	0.169	0.211,0.362,0.594	0.140,0.277,0.563	0.140,0.362,0.625	1.6,2.35,2.85
C4	0.191	0.193,0.333,0.576	0.158,0.292,0.545	0.158,0.375,0.606,	1.65,2.4,2.85
C5	0.108	0.211,0.370,0.613	0.193,0.348,0.645	0.193,0.283,0.581	1.55,2.3,2.85
C6	0.227	0.093,0.233,0.536	0.185,0.349,0.679	0.185,0.419,0.714	1.4,2.15,2.7

Using formula 19, the values of the weighted normalized decision matrix were obtained, and using formula 20, the sums of the values of the weighted normalized decision matrix were calculated for the benefit criteria. Bearing in mind that all criteria are of a benefit type (the values of all criteria must be maximized), the sums of the values of the weighted normalized decision matrix by the cost criteria were not calculated. After the defuzzification of the sum of the values of the weighted normalized decision matrix according to the benefit criteria (formula 9), the courses of action were ranked. The obtained results are shown in Table 10.

Table 10 – COPRAS weighted normalized decision matrix

$\tilde{R}$	COA1	COA2	COA3
C1	0.025,0.050,0.102	0.028,0.054,0.102	0.044,0.073,0.114
C2	0.014,0.032,0.069	0.031,0.052,0.082	0.026,0.046,0.086
C3	0.036,0.061,0.100	0.024,0.047,0.095	0.036,0.061,0.106
C4	0.037,0.064,0.110	0.030,0.056,0.104	0.044,0.072,0.116
C5	0.023,0.040,0.066	0.021,0.037,0.069	0.015,0.030,0.062
C6	0.021,0.053,0.121	0.042,0.079,0.154	0.055,0.095,0.162
$\tilde{P}_j$	0.155,0.299,0.569	0.176,0.324,0.607	0.219,0.377,0.646
P_j	0.319931286	0.346612618	0.395352904
$p = n, s = 0$ $\Rightarrow Q_j = P_j$	0.319931286	0.346612618	0.395352904
Rang	3	2	1

Based on the obtained results, it is concluded that the third course of action of the air defence missile battalion is optimal. In this example, the fuzzy-DEMATEL method ensured the prioritization of the criteria on the basis of which the course of action was chosen in the operations planning process. After presenting the subjective opinion on the mutual influence of the criteria in the questionnaire with the DEMATEL linguistic variables by the member of the operations planning group and by applying the fuzzy-DEMATEL procedure, the evaluation of the criteria was carried out in an objective way and the subjective influence of the respondents was minimized.

In the next step, the courses of action were ranked using the fuzzy-COPRAS method. Again, the members of the operations planning group gave their subjective opinions on the values of the criteria for each course of action, and the further procedure of ranking the alternatives – courses of action was carried out by using the fuzzy-COPRAS method procedure.

Bearing in mind that the rank value, in this example, is the highest for the course of action 3, it turns out that this course is also optimal; the second in rank is course of action 2, while course 1 is the weakest.

A sensitivity analysis was done through changes in the criteria's weights. The sensitivity analysis was carried out through 24 scenarios (Table 11). In each scenario, the weight of one criterion is increased (reduced) by 20%, and 40%, respectively. The weights of the other criteria are increased (decreased) so that the sum of the criteria's values is 1.

Table 11 – The sensitivity analysis of the results

$W_1 = W_{1old} \times 1.2$	$W_1 = W_{1old} \times 1.4$	$W_1 = W_{1old} \times 0.8$	$W_1 = W_{1old} \times 0.6$
$CO3 > CO2 > CO1$	$CO3 > CO2 > CO1$	$CO3 > CO2 > CO1$	$CO3 > CO1 > CO2$
$W_2 = W_{2old} \times 1.2$	$W_2 = W_{2old} \times 1.4$	$W_2 = W_{2old} \times 0.8$	$W_2 = W_{2old} \times 0.6$
$CO3 > CO2 > CO1$	$CO3 > CO2 > CO1$	$CO3 > CO2 > CO1$	$CO3 > CO2 > CO1$
$W_3 = W_{3old} \times 1.2$	$W_3 = W_{3old} \times 1.4$	$W_3 = W_{3old} \times 0.8$	$W_3 = W_{3old} \times 0.6$
$CO3 > CO2 > CO1$	$CO3 > CO2 > CO1$	$CO3 > CO2 > CO1$	$CO3 > CO2 > CO1$
$W_4 = W_{4old} \times 1.2$	$W_4 = W_{4old} \times 1.4$	$W_4 = W_{4old} \times 0.8$	$W_4 = W_{4old} \times 0.6$
$CO3 > CO2 > CO1$	$CO2 > CO3 > CO1$	$CO3 > CO2 > CO1$	$CO3 > CO2 > CO1$
$W_5 = W_{5old} \times 1.2$	$W_5 = W_{5old} \times 1.4$	$W_5 = W_{5old} \times 0.8$	$W_5 = W_{5old} \times 0.6$
$CO3 > CO2 > CO1$	$CO3 > CO2 > CO1$	$CO3 > CO2 > CO1$	$CO3 > CO2 > CO1$
$W_6 = W_{6old} \times 1.2$	$W_6 = W_{6old} \times 1.4$	$W_6 = W_{6old} \times 0.8$	$W_6 = W_{6old} \times 0.6$
$CO3 > CO2 > CO1$	$CO2 > CO3 > CO1$	$CO3 > CO2 > CO1$	$CO2 > CO3 > CO1$

The results in the table show that the ranking of the courses of action changed through four scenarios. In other scenarios, the ranking of the courses of action did not change. The correlation of the results was tested using Kendall's coefficient of concordance W. This coefficient represents a measure of the agreement between several judges (in this case 24 scenarios) who have rank ordered a set of entities (in this case three courses of action) (Field, 2005). The value of Kendall's coefficient of concordance for all 24 scenarios and 3 variables (the courses of action) is 0.845. The value of the coefficient of 0.845 is extremely significant for a significance of 0.05 (the limit value of Kendall's coefficient of concordance for 24 judges - scenarios and 3 entities - the courses of action is 0.12).Thus, it can be concluded that there is a very high correlation (closeness) of ranks through the scenarios and that the results obtained using the hybridized fuzzy-DEMATEL-COPRAS approach are credible.

To see the advantages of the proposed model, decision making in the fourth phase of the process is briefly explained by applying the Standard Procedure for Operations Planning Process (Table 12).

Table 12 – An example of a decision matrix used in the Standard Procedure for Operations Planning Process

Criteria	Coefficient	Ranking	COA1	Ranking	COA2	Ranking	COA3
C1	2	1	2	2	4	1	2
C2	1	1	1	1	1	2	2
C3	2	2	4	2	4	1	2
C4	2	2	4	1	2	2	4
C5	1	2	2	2	2	2	2
C6	3	2	6	1	3	1	3
Rang of COA			19 (3)		16 (2)		15 (1)

The coefficients in the Standard Procedure for Operations Planning Process are determined by an individual, commander or deputy commander without discussion with other members of the operational planning group. The deputy battalion commander, after consultation, proposes criteria ranks for each course of action. In the last step, the values obtained by multiplying the value of the coefficient with the rank value for each course of action are added and the course of action with the lowest value is chosen as the best. As can be noted, the process does not use scientific methods, values are assigned randomly without in-depth analysis and decision making is influenced by individuals. Bearing in mind the above, there is no doubt that the main contribution of the paper is based on the following facts: the process of the courses of action valuation is based on the application of MCDM scientific methods; group decision making reduces the influence of individuals in the group; the application of the MCDM method enables an objective approach to decision making based on the subjective opinion of the respondents. Also, the application of fuzzy sets ensures the elimination of ambiguity and indeterminacy. Namely, decision makers evaluate the criteria using linguistic variables that are transformed into triangular fuzzy sets. These fuzzy sets, in discrete form, have three values. In the middle value, the fuzzy number membership function has the maximum value, while the first and third values represent the limits of the left distribution and the right distribution of the confidence interval of fuzzy sets (in this way, the approximate value "about" was introduced into the operational planning process – for example "about 1", "about 2", etc.). This MCDM model also has its limits, which are reflected in the following: MCDM methods are mainly applied by examining experts (expertise is not carried out in the operational planning process, but group members are pre-determined from the battalion command); sometimes it is difficult for the members of the operations planning group to assess the mutual influence of the criteria due to a number of factors whose mutual influences are often intertwined; mathematical formulations are generally rejected by the members of the operations planning group due to the lack of a unique interface that would significantly facilitate the application of the MCDM model, etc. The aforementioned shortcomings can be eliminated by forming a scientific and professional team that would analyze the possibility of forming a unique MCDM model. The mentioned model would be based on professional experiences from corps units. The final design of the model would have a unique interface that would facilitate the use of the MCDM model and would resemble the information system models already used in the Army (interfaces for planning defense functions, human resources, logistical support, etc.).

Conclusion

The paper shows the possibility of applying a multi-criteria decision-making approach in the fuzzy environment with the aim of optimizing the operations planning process in air defence units. A multi-criteria optimization approach can support the decision-making process, which will minimize subjectivity. Namely, despite the fact that the subjective assessments of individuals are taken as a starting point, the scientific-methodological approach in further steps enables the objectification of the decision-making process. Multi-criteria optimization is performed using the mathematical software MATLAB, which cannot fully ensure the ease of application of these methods to the end user. Future research should be focused on creating a unique procedure for optimizing the operations planning process based on multi-criteria decision-making methods (AHP, BEST-WORST, DEMATEL, COPRAS, MABAC, TOPSIS, etc.), with the creation of a unique programming code that would be transformed into a suitable programming language. This approach would lead to the creation of a unique interface that would significantly facilitate the operations planning process for the end user. Also, in that case, the subjective influence of each individual in the operational planning process would be significantly reduced.

References

Alinezhad, A., Khalili, J., Alinezhad, A. & Khalili, J. 2019. *New Methods and Applications in Multiple Attribute Decision Making (MADM)*. Cham: Springer. Available at: https://doi.org/10.1007/978-3-030-15009-9.

Ataei, Y., Mahmoudi, A., Feylizadeh, M.R. & Li, D.-F. 2020. Ordinal Priority Approach (OPA) in Multiple Attribute Decision-Making. *Applied Soft Computing*, 86, art.number:105893. Available at: https://doi.org/10.1016/j.asoc.2019.105893.

Baykasoğlu, A. & Gölcük, İ. 2017. Development of an interval type-2 fuzzy sets based hierarchical MADM model by combining DEMATEL and TOPSIS. *Expert Systems with Applications*, 70, pp.37-51. Available at: https://doi.org/10.1016/j.eswa.2016.11.001.

Božanić, D.I., Pamučar, D.S. & Karović, S.M. 2016. Application the MABAC method in support of decision-making on the use of force in a defensive operation. *Tehnika*, 71(1), pp.129-136 (in Serbian). Available at: https://doi.org/10.5937/tehnika1601129B.

-Canadian Army Command and Staff College. 2018. *The Operational Planning Process: OPP Handbook CACSC-PUB-500.* Kingston, Ontario, Canada: Canadian Army Command and Staff College [online]. Available at: https://www.canada.ca/content/dam/dnd-mdn/army/lineofsight/files/articlefiles/en/CACSC-PUB-500-2018.pdf [Accessed: 10 May 2024].

Chang, D.Y. 1996. Applications of the extent analysis method on fuzzy AHP. *European journal of operational research*, 95(3), pp.649-655. Available at: https://doi.org/10.1016/0377-2217(95)00300-2.

Field A.P. 2005. Kendall's Coefficient of Concordance. In: Everitt, B.S. & Howell, D.C. (Eds.) *Encyclopedia of Statistics in Behavioral Science*, 2, pp.1010-1011. New York: Wiley [online]. Available at: https://discoveringstatistics.com/repository/kendall's_coefficient_of_concordance_ebs.pdf [Acessed: 05 July 2024]. ISBN: 978-0-470-86080-9

Ghorabaee, M.K., Amiri, M., Sadaghiani, J.S. & Goodarzi, G.H. 2014. Multiple criteria group decision-making for supplier selection based on COPRAS method with interval type-2 fuzzy sets. *The International Journal of Advanced Manufacturing Technology*, 75, pp.1115-1130. Available at: https://doi.org/10.1007/s00170-014-6142-7.

Gul, M., Celik, E., Aydin, N., Gumus, A.T. & Guneri, A.F. 2016. A state of the art literature review of VIKOR and its fuzzy extensions on applications. *Applied Soft Computing*, 46, pp.60-89. Available at: https://doi.org/10.1016/j.asoc.2016.04.040.

Inđić, D., Petrović, I., Ivanković, N. & Đukić, Đ. 2018. Chemical accident area reconnaissance by unmanned aircraft. *Vojno delo,* 70(8), pp.109-127. Available at: https://doi.org/10.5937/vojdelo1808109I.

Kahraman, C., Öztayşi, B., Sarı, İ.U. & Turanoğlu, E. 2014. Fuzzy analytic hierarchy process with interval type-2 fuzzy sets. *Knowledge-Based Systems*, 59, pp.48-57. Available at: https://doi.org/10.1016/j.knosys.2014.02.001.

Khan, F., Ali, Y. & Pamucar, D. 2022. A new fuzzy FUCOM-QFD approach for evaluating strategies to enhance the resilience of the healthcare sector to combat the COVID-19 pandemic. *Kybernetes*, 51(4), pp.1429-1451. Available at: https://doi.org/10.1108/K-02-2021-0130.

Opricovic, S. & Tzeng, G.-H. 2004. Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of operational research*, 156(2), pp.445-455. Available at: https://doi.org/10.1016/S0377-2217(03)00020-1.

Pamučar, D. & Ćirović, G. 2015. The selection of transport and handling resources in logistics centers using Multi-Attributive Border Approximation area Comparison (MABAC). *Expert Systems with Applications*, 42(6), pp.3016-3028. Available at: https://doi.org/10.1016/j.eswa.2014.11.057.

Petrović, J. & Petrović, I. 2021. What makes a successful helicopter pilot? A fuzzy multi-criteria decision-making approach. *International Journal for Traffic and Transport Engineering*, 11(4), pp.507-527. Available at: https://doi.org/10.7708/ijtte2021.11(4).02.

Sabaei, D., Erkoyuncu, J. & Roy, R. 2015. A Review of Multi-criteria Decision Making Methods for Enhanced Maintenance Delivery. *Procedia CIRP*, 37, pp.30-35. Available at: https://doi.org/10.1016/j.procir.2015.08.086.

Stević, Ž., Pamučar, D., Puška, A. & Chatterjee, P. 2020. Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS). *Computers & Industrial Engineering*, 140, art.number:106231. Available at: https://doi.org/10.1016/j.cie.2019.106231.

Tešić, T. & Božanić, D. 2023. Optimizing Military Decision-Making: Application of the FUCOM– EWAA–COPRAS-G MCDM Model. *Acadlore Transactions on Applied Mathematics and Statistics*, 1(3), pp.148-160. Available at: https://doi.org/10.56578/atams010303.

-UK Ministry of Defence. 2019. *Allied Joint Publication-5 Allied Joint Doctrine for the Planning of Operations. Ministry of Defence UK* [e-book]. Bristol: UK Ministry of Defence [online]. Available at: https://assets.publishing.service.gov.uk/media/6054d017e90e0724be025a8f/20210310-AJP_5_with_UK_elem_final_web.pdf [Accessed: 12 May 2024].

Yu, S.M., Wang, J. & Wang, J.Q. 2017. An Interval Type-2 Fuzzy Likelihood-Based MABAC Approach and Its Application in Selecting Hotels on a Tourism Website. *International Journal of Fuzzy Systems*, 19, pp.47-61. Available at: https://doi.org/10.1007/s40815-016-0217-6.

Zavadskas, E.K., Kaklauskas, A., Turskis, Z. & Tamošaitiene, J. 2008. Selection of the effective dwelling house walls by applying attributes values determined at intervals. *Journal of Civil Engineering and Management*, 14(2), pp.85-93. Available at: https://doi.org/10.3846/1392-3730.2008.14.3.

Zavadskas, E.K., Turskis, Z. & Kildienė, S. 2014. State of art surveys of overviews on MCDM/MADM methods. *Technological and Economic Development of Economy*, 20(1), pp.165-179. Available at: https://doi.org/10.3846/20294913.2014.892037.

Žižović, M. & Pamučar, D. 2019. New model for determining criteria weights: Level Based Weight Assessment (LBWA) model. *Decision Making: Applications in Management and Engineering*, 2(2), pp.126-137. Available at: https://doi.org/10.31181/dmame1902102z.

Mejora del proceso de planificación de operaciones mediante un enfoque híbrido de toma de decisiones difusa y multicriterio

Ivan B. Petrović[a], *Milan* Ž. Milenković[b]

[a] Universidad de Defensa de Belgrado, Academia Militar,
Belgrado, República de Serbia, **autor de correspondencia**

[b] Universidad de Defensa de Belgrado, Escuela de Defensa Nacional
"Mariscal de campo Radomir Putnik", Belgrado, República de Serbia

CAMPO: matemáticas aplicadas, ciencias militares
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: En el artículo se muestra la posibilidad de optimizar la toma de decisiones en el proceso de planificación de operaciones en unidades de defensa aérea mediante la aplicación de un enfoque de toma de decisiones multicriterio en un entorno difuso. Analizando el contenido de la bibliografía disponible, se determinaron los criterios de selección a partir de los cuales es posible evaluar y comparar los planes de acción de las unidades de defensa aérea. Los criterios se basan en los parámetros de evaluación de los planes de acción de la matriz de decisión en la fase del proceso de planificación de operaciones denominada los planes de acción validación y comparación.

Métodos: El enfoque propuesto combina el Laboratorio de Pruebas y Evaluación de la Toma de Decisiones (DEMATEL) y la Evaluación Proporcional Comprimida (COPRAS) que han sido modificados con éxito mediante conjuntos triangulares difusos. Se aplicó el método difuso-DEMATEL para determinar los pesos de los criterios y el método difuso-COPRAS para evaluar las alternativas - planes de acción.

Resultados: Se integraron múltiples métodos de toma de decisiones difusos y multicriterio en un modelo único que se puede aplicar en el proceso de planificación de operaciones con el objetivo de optimizar el proceso de toma de decisiones.

Conclusión: El artículo contribuye a la ciencia militar en la toma de decisiones relacionadas con el proceso de planificación de operaciones a nivel táctico en unidades de defensa aérea.

Palabras claves: Toma de Decisiones Multicriterio (MCDM), DEMATEL, COPRAS, Conjuntos Difusos Triangulares, Proceso de Planificación de Operaciones.

Совершенствование процесса планирования операций с использованием гибридного нечетко-многокритериального подхода к принятию решений

Иван Б. Петрович[а], *Милан* Ж. Миленкович[б]

[а] Университет обороны в г. Белград, Военная академия,
г. Белград, Республика Сербия, **корреспондент**

[б] Университет обороны в г. Белград, Школа национальной обороны,
«Фельдмаршал Радомир Путник», г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 27.47.19 Исследование операций,
28.17.31 Моделирование процессов управления
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В статье представлена возможность оптимизации процесса принятия решений по планированию операций в подразделениях противовоздушной обороны путем применения многокритериального подхода к принятию решений в нечеткой среде. С помощью анализа содержания доступной литературы были определены критерии отбора, на основании которых можно оценивать и сравнивать действия подразделений противовоздушной обороны. Критерии основаны на параметрах оценки вариантов действий из матрицы принятия решений на этапе процесса сравнения вариантов применения.

Методы: Предлагаемый подход объединяет лабораторные испытания и оценку процесса принятия решений (DEMATEL) с методом комплексной пропорциональной оценки (COPRAS), которые были успешно модифицированы с помощью нечеткого треугольного числа. Для определения весовых коэффициентов критериев был применен метод fuzzy-DEMATEL, а для оценки альтернатив – вариантов действий был применен метод fuzzy-COPRAS.

Результаты: Несколько нечетких многокритериальных методов принятия решений были интегрированы в единую модель, которая может быть применена в процессе планирования операций с целью оптимизации процесса принятия решений.

Выводы: Данная статья вносит вклад в военную науку, в частности, в области принятия решений, связанных с процессом планирования операций на тактическом уровне в подразделениях противовоздушной обороны.

Ключевые слова: многокритериальное принятие решений (MCDM), DEMATEL, COPRAS, треугольные нечеткие числа, процесс планирования операций.

Унапређење процеса оперативног планирања применом хибридног фази-вишекритеријумског приступа одлучивању

Иван Б. Петровић[а], *Милан* Ж. Миленковић[б]

[а] Универзитет одбране у Београду, Војна академија,
Београд, Република Србија, **аутор за преписку**

[б] Универзитет одбране у Београду, Школа националне одбране
„Војвода Радомир Путник”, Београд, Република Србија

ОБЛАСТ: примењена математика, војне науке
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У раду је приказана могућност оптимизације доношења одлука у процесу оперативног планирања у артиљеријско-ракетним јединицама за противваздухопловна дејства применом метода вишекритеријумског одлучивања у фази окружењу. Анализом садржаја доступне литературе, одређени су критеријуми на основу којих је могуће вредновати и поредити варијанте употребе артиљеријско-ракетних јединица за противваздухопловна дејства које развијају чланови групе за оперативно планирање у току процеса оперативног планирања. Критеријуми се заснивају на параметрима оцењивања варијанти употребе из матрице одлучивања у фази поређења варијанти употребе.

Методе: Предложени приступ који комбинује методе ДЕМАТЕЛ и КОПРАС успешно је модификован троугластим фази скуповима. Метода фази-ДЕМАТЕЛ примењена је за одређивање тежине критеријума, а фази-КОПРАС метода за вредновање алтернатива – варијанти употребе.

Резултати: Интегрисано је више фази-вишекритеријумских метода одлучивања у јединствен модел који се може применити у процесу планирања операција ради оптимизације процеса доношења одлука.

Закључак: Рад доприноси војној науци приликом доношења одлука у процесу оперативног планирања на тактичком нивоу у артиљеријско-ракетним јединицама за противваздухопловна дејства.

Кључне речи: вишекритеријумско одлучивање (ВКО), ДЕМАТЕЛ, КОПРАС, троугласти фази скупови, оперативно планирање.

Paper received on: 06.02.2024.
Manuscript corrections submitted on: 24.09.2024.
Paper accepted for publishing on: 25.09.2024.