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Application of fermatean fuzzy weight operators and MCDM model DIBR-DIBR II-NWBM-BM for efficiency-based selection of a complex combat system

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Abstract

The use of complex automated combat systems is a basic feature of every modern combat operation, and all modern armies strive to implement such systems in their units. This paper investigates the choice of a complex combat system based on the efficiency criteria that condition it. The Defining Interrelationships Between Ranked criteria (DIBR) and the Defining Interrelationships Between Ranked criteria II (DIBR II) methods were used to determine the weight coefficients of the criteria, which proved to be effective in assessing the importance of each criterion in the context of making complex decisions. Aggregation of expert opinions, for each of the methods, was performed using the Normalized Weighted Bonferroni Mean (NWBM) operator. After the weight coefficients for both methods were obtained, the aggregation of the obtained values was performed using the Bonferroni Mean (BM) operator, which resulted in the final values of the weight coefficients of the criteria. In order to choose the optimal alternative, the Fermatean Fuzzy Weight Operators (FFWO) and BM operator were used. These operators contributed to the precise evaluation and ranking of alternatives, taking into account their characteristics and specificities. Furthermore, the paper analyzed the sensitivity of the output results to changes in the weight coefficients of the criteria. This is important in order to assess the stability of the Multiple Criteria Decision Making (MCDM) model and ensure its reliability in different scenarios. This work represents a significant contribution to the field of decision-making in this context and provides a useful framework for the selection of complex combat systems, and the combination of different methods and operators enables a comprehensive analysis and optimization of the research problem.

Keywords: DIBR, DIBR II, NWBM, FFWO, MCDM, selection, complex combat systems.

1. Introduction

Modern combat operations require the use of automated complex combat systems, whether manned or unmanned, which increase the combat power of military units and the very efficiency of the system, as a function of ''the availability, credibility, and capability of a weapon system that can be used to perform a set of specific missions'' (Hu et al., 2022). All the armies of the world strive to acquire or develop such systems (unmanned aerial vehicles, airplanes, combat helicopters, artillery pieces, submarines, warships, anti-aircraft defense systems, etc.). Today, it is difficult to imagine an army that does not use such systems or at least is not in the process of acquiring them. Procurement decision makers (DM) are faced with the problem of choosing the optimal complex combat system, which requires consideration of several aspects that condition the choice in question. Assistance to DM in various choices and evaluations can be provided by various decision support systems, models and methods (Božanić and Pamučar, 2010; Pamučar et al., 2011a; Pamučar et al., 2011b; Pamučar et al., 2012; Pamučar et al., 2016; Torkayesh et al., 2020; Mondal et al., 2021; Dağıstanlı, 2023; Sahoo and Goswami, 2023; Gokasar and Karaman, 2023; Badi et al., 2023; etc.)

Different authors choose combat systems in different ways. Ardil (2023a) selects a combat drone using the Fuzzy Proximity Measure (FPM) method and the Preference Analysis for Reference Ideal Solution (PARIS) method (Ardil, 2023b), considering tactical, operational, strategic, technical, and economic criteria. Also, Ardil (2022) using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method in a fuzzy environment, for select a fighter aircraft, based on the tactical and technical characteristics of the aircraft, while in (Ardil, 2021) the author compares the results of different MCDM methods for the subject selection. Tenório et al. (2020) choose a warship for the needs of the Brazilian Navy using the Multicriteria Decision Aiding Hybrid Algorithm (THOR). Dwivedi and Sharma (2023) also choose a fighter plane for the needs of the Indian Army, using the Entropy-VIKOR (VIsekriterijumsko-KOmpromisno Rangiranje) MCDM model. By applying the MCDM algorithm presented in the paper, Kulik (2021) selects the optimal anti-aircraft defense system based on the combat capabilities of the system. Sun et al. (2021) defines the weight coefficients of the criteria for the selection of a combat drone, based on efficiency, using an improved version of the Entropy method and the Analytic Hierarchy Process (AHP) method. Wang et al. (2020) evaluate the ship's combat system based on combat efficiency, using the AHP method, etc.

In this paper, a DIBR-DIBR II-NWBM-BM-FFWO MCDM model is presented for decision support in the selection of a complex combat system based on efficiency. From FFWO, the following operators were used: Fermatean fuzzy weighted average (FFWA), Fermatean fuzzy weighted geometric (FFWG), Fermatean fuzzy weighted power average (FFWPA) and Fermatean fuzzy weighted power geometric (FFWPG). The research was designed as follows: first, the criteria and their weight coefficients were identified, and then the optimal alternative was selected from the set of offers. Then, an analysis of the sensitivity of the output results of the model to the change in the weight coefficients of the criteria was performed, and the obtained results were discussed. At the end, concluding remarks are given regarding the results of the research, limitations, and directions of future research.

2. Materials and methods

Figure 1 shows the algorithm of the proposed methodology.

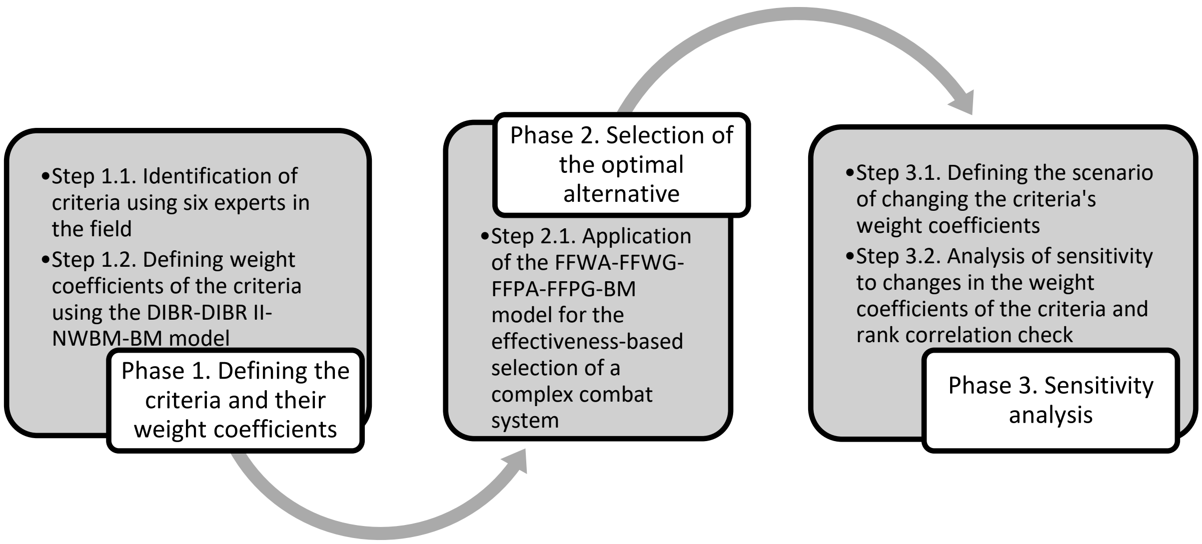

Figure 1. Algorithm of the MCDM model DIBR-DIBR II-NWBM-BM-FFWO

In the following text, the phase and steps of the MCDM model are operationalized theoretically. At the beginning, the criteria were identified.

2.1. Identification of criteria

By analyzing the available literature and engaging six experts in the field, five criteria were identified that determine the choice of a complex combat system based on efficiency, shown in Table 1.

Table 1. Criteria for choosing a complex combat system

Criterion name	Criteria description	Character of criteria
C1 - Probability of hitting the target	It represents the ratio between the number of missiles fired at the target and the number of hits on the target.	Benefit
C2 - Response time	It represents the total time required for the reaction of the control and executive part of the combat system (Kovač, et al., 2006).	Cost
C3 - Data processing capacity	It represents the ability (speed) of the processor of a complex combat system, that is, the number of operations that the processor can perform in a certain period. It is expressed in GHz, that is, in MIPS (Million Instructions Per Second) or MFLOPS (Million Floating Point Operations Per Second).	Benefit
C4 - Management efficiency	It implies the efficiency of the system to collect and transmit the necessary data about the targets, to select the target, to calculate the elements for hitting the target and transfer them to the fire systems of the means, which will perform the action on the target, as well as to determine the effects of the action on the target (Kovač et al., 2006).	Benefit
C5 - Effectiveness of cooperation	It refers to the success of the cooperation of the complex combat system with other participants in the operation, i.e., the effectiveness of the exchange of information and plans in connection with the execution of the given task, as well as joint action on the battlefield (Fan et al., 2017).	Benefit

2.2. Description of the methods used to calculate the weight coefficients of the criteria

The DIBR was first presented in (Pamucar et al., 2021) and has so far found its application in various fields for determining the weight coefficients of criteria: Engineering, Energy, Computer Science, Business, Management and Accounting, Social Sciences, Mathematics and Environmental Science (Scopus, 2023a; Ayough et al., 2023; Deveci et al., 2022; Pamucar et al., 2021; Tešić et al., 2022; Tešić et al., 2023; Pamucar et al., 2022). The mathematical formulation of the DIBR method is shown in Pamucar et al. (2021).

The DIBR II method is an improved version of the DIBR method and represents a young method for determining the weight coefficients of the criteria, published at the end of April 2023 (Božanić and Pamučar, 2023). So far, only two papers have been published where the method was applied in the areas of social media and the automotive industry (Božanić and Pamučar, 2023), as well as in the field of Lean organization systems management (Božanić, et al., 2023a). Considering that it is a method that has not been applied in many cases, the mathematical formulation of the DIBR II method is given below (Božanić and Pamučar, 2023; Božanić et al., 2023a):

Step 1. Identification of criteria. First, a set of criteria is defined (*C*), where is $C=\{C_1,C_2,...,C_n\}$.

Step 2. Ranking criteria. In this step, the criteria are ranked in order of importance, from most important to least important $C_1>C_2>...>C_n$.

Step 3. Defining the relationship between the criteria. First, relationships are defined between adjacent criteria $\upsilon_{n,n+1}$, that is, how many times is C_n more significant than the criteria C_{n+1}, on the basis of which the following relations are defined:

$$\omega_1:\omega_2=\upsilon_{1,2}:1\mapsto\frac{\omega_1}{\omega_2}=\upsilon_{1,2} \tag{1}$$

$$\omega_2:\omega_3=\upsilon_{2,3}:1\mapsto\frac{\omega_2}{\omega_3}=\upsilon_{2,3} \tag{2}$$

...

$$\omega_{n-1}:\omega_n=\upsilon_{n-1,\mathrm{n}}:1\mapsto\frac{\omega_{n-1}}{\omega_n}=\upsilon_{n-1,\mathrm{n}} \tag{3}$$

where ω_n represents the weight coefficient of the observed criterion.

Then, the relationship between the first-ranked C_1 and the last-ranked criteria C_n is defined.

$$\omega_1:\omega_n=\upsilon_{1,\mathrm{n}}:1\mapsto\frac{\omega_1}{\omega_n}=\upsilon_{1,\mathrm{n}} \tag{4}$$

Step 4. Defining the relationship between the most important and other criteria. Based on expressions (1)-(3), the following mathematical expression is arrived at:

$$\omega_2=\frac{\omega_1}{\upsilon_{1,2}} \tag{5}$$

and introducing expression (5) leads to the following expression:

$$\omega_3=\frac{\omega_2}{\upsilon_{2,3}}=\frac{\omega_1}{\upsilon_{1,2}.\upsilon_{2,3}} \tag{6}$$

...

In the same way, the relationship between the least significant criterion and the others is reached:

$$\omega_n = \frac{\omega_1}{\upsilon_{1,2}.\upsilon_{2,3}.\ldots.\upsilon_{n-1,n}} \tag{7}$$

Step 5. Determination of the weight coefficient of the most important criterion C_1. It is done by applying expression (8).

$$\omega_1 = \frac{1}{1+\frac{1}{\upsilon_{1,2}}+\frac{1}{\upsilon_{1,2}.\upsilon_{2,3}}+\cdots+\frac{1}{\upsilon_{1,2}.\upsilon_{2,3}.\ldots.\upsilon_{n-1,n}}} \tag{8}$$

Step 6. Determination of the weight coefficients of the remaining criteria. The aforementioned is done by implementing the obtained criterion coefficient ω_1 in expressions (5)-(7).

Step 7. Evaluation of the quality of defined relationships. In order to confirm the quality relations between the criteria, it is necessary that the value of the deviation D_n of the criteria C_n is in the range $0 \le D_n \le 0.1$. The value D_n is obtained by applying expression (9).

$$D_n = \left|1 - \frac{\omega_n}{\omega_n^k}\right| \tag{9}$$

where ω_n^k represents the control value of the weight coefficient of the criterion C_n and is obtained by applying expression (10).

$$\omega_n^k = \frac{\omega_1}{\upsilon_{1,n}} \tag{10}$$

The mentioned control is performed for the most significant and the least significant criterion, where the values of I should be approximately equal, that is, a deviation of up to 10% is allowed. In cases where the stated conditions are not met, it is necessary to redefine the relations between neighboring criteria (more in Božanić and Pamučar, 2023), otherwise the relations are well defined.

The NWBM operator (Zhou, et al., 2019) was used in the paper to aggregate the opinions of six experts for defining the weight coefficients of the criteria in the DIBR and DIBR II method. The mathematical expression for the NWBM operator is given below (Zhou, et al., 2019):

$$NWBM^{r,s}(x_1, x_2, \ldots, x_n) = \left(\sum_{i,j=1}^{n} \frac{\omega_i \omega_j}{1-\omega_i} x_i^r x_j^s \right)^{\frac{1}{r+s}} \tag{11}$$

where $x_1, x_2, \ldots, x_n$ represents the set of positive numbers, $r, s \ge 0$ represent the stabilization parameters of the function, and ω_{ij} weight coefficients of experts' competencies.

The BM operator (Bonferroni, 1950; Zhou, et al., 2019) was used in the paper to aggregate the weight coefficients of the criteria, obtained by applying the DIBR and DIBR II method.

$$BM^{r,s}(x_1, x_2, \ldots, x_n) = \left(\frac{1}{n(n-1)} \sum_{\substack{i,j=1 \\ i \ne j}}^{n} x_i^r x_j^s \right)^{\frac{1}{r+s}} \tag{12}$$

2.2. Model FFWA-FFWG-FFPA-FFPG-BM for choosing the optimal alternative

Fermatean fuzzy sets and numbers have been used in numerous papers, due to their characteristic of handling imprecision and uncertainty well (Akram et al., 2023a; Saha et al., 2023; Simic et al., 2023; Akram et al., 2023b; Mishra et al., 2023; Akram et al., 2023c; Deveci et al., 2023; Chakraborty and Saha, 2023; Görçün et al., 2023; Chang et al., 2023; Fahmi et al., 2023; Senapati and Yager, 2019; Senapati and Yager, 2020; etc.) and in different areas of research, such as: Computer Science, Mathematics, Engineering, Decision Sciences, Business, Management and Accounting, Energy, Social Sciences, Environmental Science, Physics and Astronomy, Materials Science, Chemistry, Multidisciplinary, Arts and Humanities, Economics, Econometrics and Finance, Agricultural and Biological Sciences, Psychology, Medicine, and Chemical Engineering (Scopus, 2023b). More on Fermatean fuzzy sets can be seen in (Senapati and Yager, 2020).

The methodology for choosing the optimal alternative is based on the research "Fermatean fuzzy weighted averaging/geometric operators and its application in multi-criteria decision-making methods" (Senapati and Yager, 2019), with improvement reflected in the aggregation of ranks obtained by operators FFWA, FFWG, FFPA and FFPG by applying the BM operator (12) and obtaining the final ranks of alternatives.

3. Results

Given that in Section 2.1. identified criteria, the next step within the first stage of the MCDM algorithm (Figure 1) is the determination of the weight coefficients of the criteria. Using the DIBR method, the weight coefficients for all six experts were determined $E=\{E_1,E_2,...,E_n\}$ (Table 2).

Table 2. Values of the weight coefficients of the criteria obtained using the DIBR method for each of the experts

	w_1	w_2	w_3	w_4	w_5
E_1	0.246505	0.201686	0.193776	0.186177	0.171856
E_2	0.244437	0.208224	0.192207	0.184669	0.170464
E_3	0.262646	0.214892	0.190565	0.175906	0.155992
E_4	0.246505	0.201686	0.193776	0.186177	0.171856
E_5	0.246505	0.201686	0.193776	0.186177	0.171856
E_6	0.231855	0.205607	0.197544	0.189797	0.175197

By aggregating the values of the weight coefficients obtained by expert opinion, using the NWBM operator, expression (11), the final results of the DIBR method, i.e., the weight coefficients of the criteria, are reached (Table 3). The values of the weight coefficients of the experts' competences are $\omega_e=\{0.16,0.18,0.17,0.16,0.17,0.16\}$.

Table 3. The final values of the weight coefficients of the criteria obtained using the DIBR method

	w_1	w_2	w_3	w_4	w_5
DIBR method	0.246542	0.205738	0.193551	0.184741	0.169450

By applying the steps of the DIBR II method, expressions from (1) to (10), the weight coefficients for each of the experts were also defined (Table 4).

Table 4. Values of weight coefficients of the criteria obtained using the DIBR II method for each of the experts

	w_1	w_2	w_3	w_4	w_5
E_1	0.245701	0.204751	0.195001	0.185715	0.168832
E_2	0.244059	0.212225	0.192932	0.183744	0.167040
E_3	0.245701	0.204751	0.195001	0.185715	0.168832
E_4	0.256035	0.213363	0.193966	0.176333	0.160303
E_5	0.254096	0.211746	0.192497	0.174997	0.166664
E_6	0.245701	0.204751	0.195001	0.185715	0.168832

After aggregating the values of the weight coefficients obtained by expert opinion, using the NWBM operator, the final results of the DIBR II method are reached, i.e., the weight coefficients of the criteria (Table 5).

Table 5. The final values of the weight coefficients of the criteria obtained using the DIBR II method

	w_1	w_2	w_3	w_4	w_5
DIBR II method	0.248489	0.208665	0.194037	0.182040	0.166778

Further aggregation of the values of the weight coefficients of the criteria, obtained using the DIBR (Table 3) and DIBR II method (Table 5), using the BM operator, expression (12), leads to the final values of the weight coefficients of the criteria, which will be implemented in the model for choosing the optimal alternatives (Table 6).

Table 6. The final values of the weight coefficients of the criteria

	w_1	w_2	w_3	w_4	w_5
The final values of the weight coefficients of the criteria	0.247516	0.207195	0.193798	0.183385	0.168106

After determining the weight coefficients of previously identified criteria, the definition of alternatives is approached. For the purposes of testing the model, four alternatives were defined, i.e., four different complex combat systems of the same purpose $A=\{A_1, A_2, A_3, A_4\}$. For the purposes of evaluating alternatives, according to each criterion, a linguistic scale is used, based on FFN (Fermatean fuzzy numbers), presented in Table 7.

Table 7. Linguistic scale for evaluating alternatives

Scale	FFN
Satisfies (S)	(0.9, 0.1)
Partially satisfying (PS)	(0.7, 0.3)
Partially unsatisfactory (PU)	(0.3, 0.7)
It does not satisfy (NS)	(0.1, 0.9)

The next step represents the formation of the initial decision-making matrix (Table 8).

Table 8. Initial decision-making matrix

	C_1	C_2	C_3	C_4	C_5
	Benefit	Cost	Benefit	Benefit	Benefit
A_1	S	PS	NS	S	PU
A_2	PU	S	S	NS	S
A_3	S	PU	S	S	PS
A_4	PS	NS	PS	S	S

By applying the proposed methodology, the following values of the score and accuracy function are reached for each of the alteratives (Table 9).

Table 9. Score and accuracy function values for each of the alternatives

	A_1		A_2		A_3		A_4	
FFWA	0.519781	0.480219	0.439026	0.560974	0.824940	0.175060	0.811737	0.188263
Score	0.029687		0.091914		0.556028		0.528195	
Accuracy	0.251174		0.261153		0.566757		0.541540	
FFWG	0.389267	0.317758	0.290696	0.381842	0.818993	0.151030	0.805519	0.162390
Score	0.026901		0.031109		0.545895		0.518387	
Accuracy	0.091069		0.080239		0.552785		0.526951	
FFWPA	0.687149	0.646680	0.647049	0.717901	0.835932	0.220754	0.823596	0.231919
Score	0.054016		0.099091		0.573376		0.546179	
Accuracy	0.594891		0.640894		0.594891		0.571127	
FFWPG	0.758398	0.695955	0.724962	0.771371	0.853691	0.221303	0.843158	0.232442
Score	0.099117		0.077957		0.611321		0.586854	
Accuracy	0.773294		0.839995		0.632998		0.611972	

Aggregation of score functions obtained by different FFWOs using the BM operator, expression (12), leads to the final ranks of alternatives (Table 10).

Table 10. Final ranking of alternatives

Alternatives	Rank
A_1	4
A_2	3
A_3	1
A_4	2

Based on the score functions (Table 9) and Table 10, it can be concluded that the optimal solution is the alternative (complex combat system) A_3, while the alternative A_1 cannot in any case represent the solution of the choice in question.

4. Sensitivity analysis

In order to establish the sensitivity of the proposed methodology for the selection of a complex combat system, it is necessary to perform a sensitivity analysis, in one of the ways (Bakir et al., 2021; Muhammad et al., 2021; Puška et al., 2021; Božanić et al. al., 2022; Gergin et al., 2022; Eremina et al., 2022; Puška et al., 2023; Božanić et al., 2023b; etc). In the paper, an analysis was applied to the changes in the weight coefficients of the criteria by forming 15 scenarios of weight changes, shown in Figure 2. In the first scenario, the weights of all criteria are identical, while the other scenarios are formed in such a way that a certain value is subtracted from the most significant criterion and equally assigned to the other criteria.

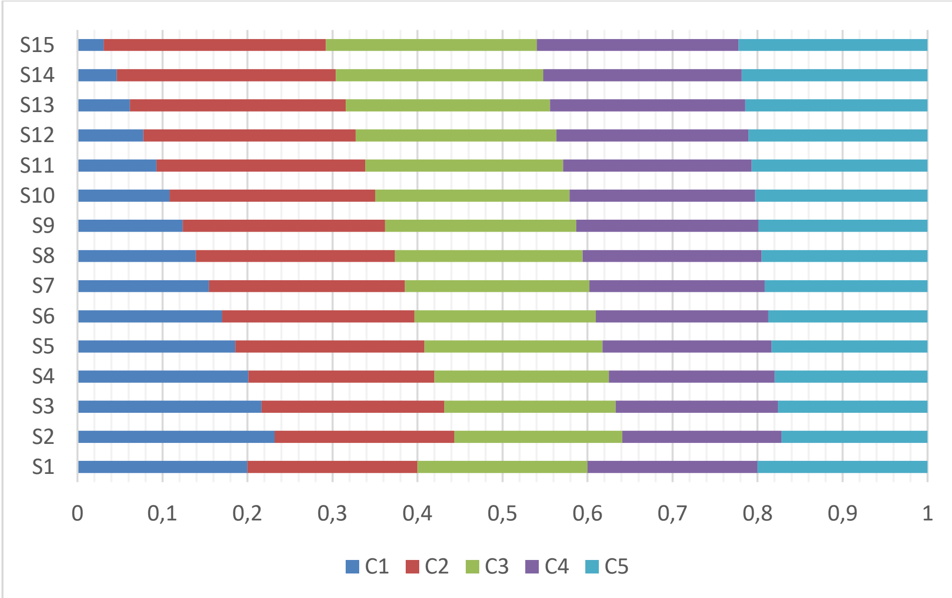

Figure 2. Scenarios of changing the weight coefficients of the criteria

By applying the proposed methodology and formed scenarios, the ranks of alternatives in all scenarios are reached (Figure 3).

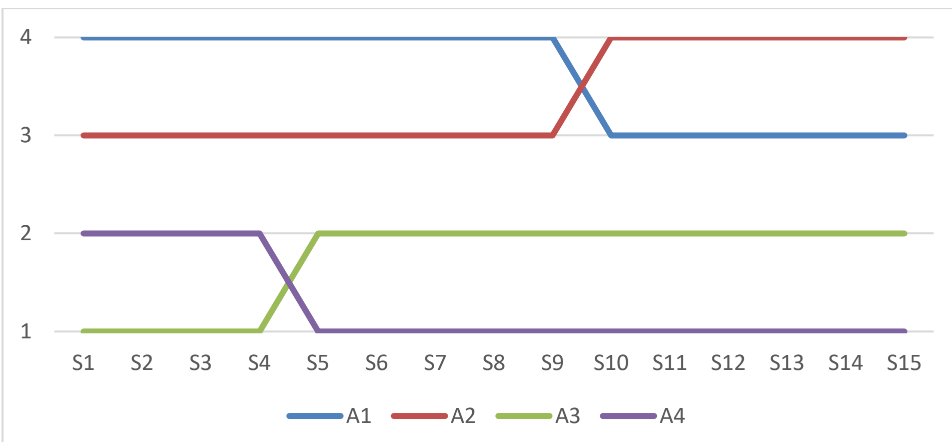

Figure 3. Alternative ranks obtained after changing criteria weights

Based on the obtained results and Figure 3, it can be concluded that alternative A_3 is a solution to this research problem, while alternative A_1 cannot be. Also, there is a noticeable change in the ranks from scenarios S_5 and S_{10}, but it is a minor and expected change, given the changes in the value of the weight coefficients of the criteria. In scenario S_1, that is, when the values of the weight coefficients of the criteria are equal, the differences in the score function of alternatives A_3 and A_4 are insignificant. Based on all the above, it can be concluded that the proposed methodology is stable.

In relation to the final ranking of the alternatives (Table 11) and the rankings obtained based on the scenario of changing the weight coefficients of the criteria (Figure 3), the calculation of the Spearman’s correlation coefficient of the ranks was performed (Tešić et al., 2023), and its values are shown in Figure 4.

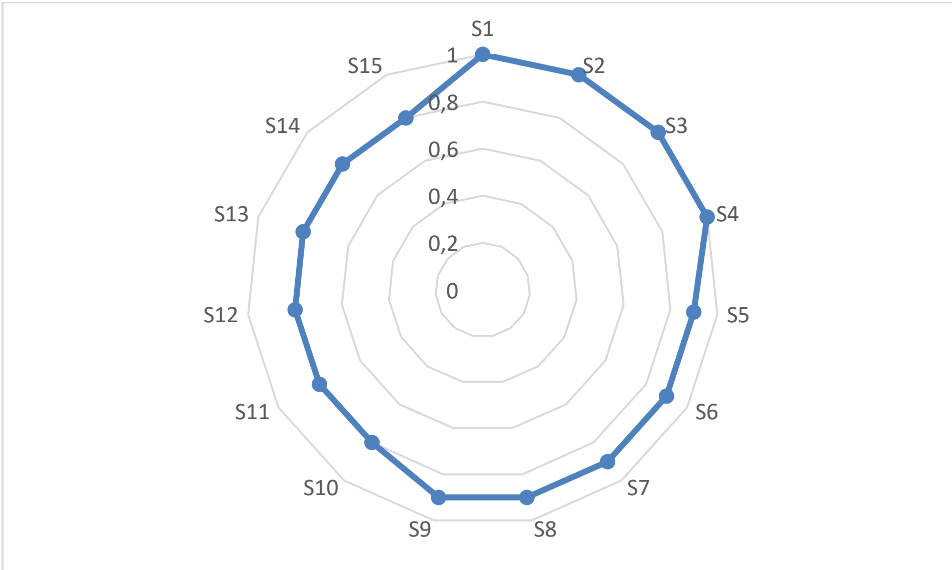

Figure 4. Spearman’s rank correlation coefficient values

The values of Spearman's rank correlation coefficient in all scenarios tend towards the ideal positive correlation, and it can be concluded that there is a correlation of ranks, i.e. that there are no significant changes in them.

5. Conclusion

Modern warfare is characterized by the extensive use of complex combat systems, which significantly changes the way conflicts are conducted and creates a new framework for military operations. These systems use highly advanced technology and connect various military platforms to achieve their objectives. This transformation in the military sense enables more efficient execution of operations and requires a deeper integration of different military capabilities. The secret of successful modern warfare lies in the ability to manage and coordinate these complex combat systems, as well as selecting the optimal system in relation to previously defined criteria.

The paper presents the efficiency-based MCDM model DIBR-DIBR II-EWAA-BM-FFWO for the selection of a complex combat system for military use. The DIBR and DIBR II methods were used to determine the weight coefficients of the criteria, while the expert opinions of six experts in each of the methods were aggregated using the NWBM operator, and the results obtained by these methods were aggregated using the BM operator. After obtaining the final values of the criterion weight coefficients, the selection of the optimal alternative, that is, the optimal complex combat system, based on their efficiency, was started. For selection purposes, FFWO, specifically FFWA, FFWG, FFWPA and FFWPG operators were used, whose score functions were aggregated using the BM operator, thus obtaining the final ranking of alternatives. As the optimal alternative, alternative A_3 is indicated, while alternative A_1 is ranked last.

In order to determine the behavior of the proposed methodology on the change of the weight coefficients of the criteria, a sensitivity analysis was performed. The results of the subject analysis indicate that the presented MCDM is stable, as well as that the ranks obtained by changing the weights of the criteria tend to an ideal correlation, which is shown by means of the Spearman's rank correlation coefficient.

The mentioned MCDM model showed the stability of the output results and its practical usability on the specific problem. The limitations of this research are reflected in the very formulation of the research problem, i.e. in the choice based only on the aspect of the effectiveness of complex combat systems, without considering other aspects such as economic, structural and similar, which will represent future directions of research in this area, as well as the application of other MCDM methods, different operators and areas that handle inaccuracies and uncertainty well.

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