

Application of the Fuzzy DIBR II–MABAC Model in the Selection of Position Area and Target

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ABSTRACT

The paper introduces a hybrid decision-making model that integrates the fuzzy Defining Interrelationships Between Ranked Criteria II (fuzzy DIBR II) and fuzzy Multi-Attributive Border Approximation Area Comparison (fuzzy MABAC) methods to determine the optimal initial and final projectile positions for maximizing operational effectiveness. Evaluation criteria were established by experts in Military Sciences. The DIBR II method was applied to calculate the criteria weighting coefficients. Crisp values are appropriate when uncertainty is low and input parameters are clearly defined, whereas fuzzy values are more suitable in contexts characterized by higher uncertainty. Given the numerous uncertain factors in the problem under consideration, the use of fuzzy numbers is well justified. The fuzzy MABAC method was subsequently employed to rank four feasible alternatives and identify the most favorable projectile positions.

To assess the robustness of the proposed model, a sensitivity analysis was conducted by varying the values of the criterion with the highest weighting coefficient. In addition, a comparative analysis was performed by individually modifying the criteria values for each alternative, with the resulting rankings compared against the initial outcomes. The model consistently identified alternative A3, associated with steep terrain, as the optimal solution, thereby demonstrating its reliability in supporting the selection of projectile positions under conditions of uncertainty.

1. Introduction

Accelerated technological development has increasingly underscored the strategic importance of airspace in the emergence of modern security threats, particularly through the introduction of remotely piloted aircraft. At the same time, unmanned ground platforms are also becoming prominent, accompanied by the growing significance of the “information” dimension of warfare. Other domains of combat—on land and at sea—are keeping pace with these developments in airspace through the computerization of combat systems and the reduction of personnel requirements, as discussed by Biletskyi *et al.* [1] and Glišin & Petrović [2].

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Mortars and machine guns are military assets that, despite technological advances, have not undergone significant transformation. Instead, they have been mounted on platforms with enhanced automation, as discussed by Drábek *et al.* [3] and Mosser [4]. A weapon system that combines the characteristics of these two is the automatic grenade launcher. It has a greater mass than a machine gun but also a longer firing range. At the same time, it is lighter and has a shorter range than a mortar. It is capable of direct, semi-indirect, and indirect fire using either the lower or upper group of firing angles. What is less well known is that, unlike mortars, whose minimum firing range is less than 100 m, the minimum firing range of an automatic grenade launcher is 1000 m. Therefore, to engage a target with a high-angle trajectory behind an obstacle, the weapon must be positioned at least 1000 m from the obstacle, as can be seen in the Rulebook for the 30 mm M93 Automatic Grenade Launcher [5]. Owing to its capability to fire along a high-angle trajectory, it is suitable for firing from depressions, ravines, and reverse slopes, as well as for engaging targets located in depressions, ravines, or behind obstacles on reverse slopes. Automatic grenade launchers are assigned to infantry companies and may either become part of the company fire support group or be distributed among platoons, depending on the specific tactical situation and terrain configuration.

The paper is based on the selection of a fire position that is directly related to the target area where the target is expected to appear on the reverse slope of the terrain behind a specific natural or artificial obstacle, such as a hill or depression. In order to select the location on the terrain where the grenade will have the most favorable effect on the target, it is necessary to establish a fire position behind the target area at an appropriate distance, in accordance with the weapon's firing range. The target engaged by the grenade launcher is an area target (a group of soldiers or the crew of a weapon system on the move, and only rarely an individual) that may appear within a designated area. The paper aims to provide decision-makers with support in selecting the most suitable fire position in accordance with the target area where the grenade is expected to achieve the greatest effectiveness. Firing data for area fire will be prepared for this target area, and fire adjustment will be carried out accordingly. The objective of the paper is to develop a model based on the proposed methods that will support decision-makers in selecting both the fire position area and target areas behind obstacles, thereby reducing the possibility of incorrect decision-making through timely preparation, occupation of the fire position, preparation of firing data, and execution of fire adjustment. Similar problems have also been addressed by Zhao *et al.* [6].

Using the fuzzy Defining Interrelationships Between Ranked Criteria II (DIBR II) method, the weighting coefficients of the criteria influencing the selection of the terrain slope in the target area within the weapon's effective firing range are determined. Experts in the field of Military Sciences—tactics and weapon systems—identified six criteria, based on the current operating procedures for the weapon and firing experience, which directly affect the selection of the fire position in relation to the expected location of a potential area target. The paper focuses on selecting the target area where the grenade is expected to achieve the most favorable effect on the target. Depending on the target location, the weapon should be positioned at the most suitable terrain, at a distance of 1000 to 1730 m behind the target area, by selecting an appropriate fire position. The selection of a specific target area from four possible alternatives is carried out using the fuzzy Multi-Attributive Border Approximation Area Comparison (MABAC) method.

An analysis of the literature indicates that multi-criteria decision-making (MCDM) methods and fuzzy logic have been widely applied in both military and civilian domains. Božanić & Pamučar [7] evaluated river crossing locations using fuzzy logic. Pamučar *et al.* [8] selected fire positions for a brigade artillery group in a defensive operation by applying a hybrid fuzzy Analytic Hierarchy Process - Technique for Order Preference by Similarity to Ideal Solution (AHP–TOPSIS) model and a fuzzified Saaty scale. Sennaroglu & Celebi [9] addressed the military airport location selection problem using

the AHP, Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE) and Multi-Criteria Optimization and Compromise Solution (VIKOR) methods. Pamučar *et al.* [10] focused on selecting optimal locations for water obstacles. Karataş *et al.* [11] investigated the military facility location problem. Radovanović *et al.* [12] selected the most efficient procedure for zeroing the optical sight of a long-range rifle using a hybrid fuzzy AHP–VIKOR model. Petrović & Kankaraš [13] presented a case study on the selection and evaluation of criteria for determining the location of an air traffic control station. Hamurcu & Eren [14] selected the best motorcycle route in Ankara using the AHP and TOPSIS methods. Stoilova [15] identified the optimal railway route in emergency situations using the AHP and Sequential Interactive Model for Urban Systems (SIMUS) methods. Liang *et al.* [16] and Xu *et al.* [17] addressed route selection for vehicles transporting perishable goods. Mihajlović *et al.* [18] selected a location for the construction of a fruit supply logistics center in the southern and eastern regions of Serbia. Küçükaydın & Aras [19] conducted a comprehensive review of facility location problems, while Contreras & O’Kelly [20] investigated hub location problems in the design of transportation and telecommunication networks. Pan *et al.* [21] carried out a case study on selecting the most suitable pedestrian overpass location for elevator installation in Singapore using an adaptive Bayesian network. Kouaied *et al.* [22] applied fuzzy AHP in the field of hydrology in Tunisia. Jokić *et al.* [23] selected fire positions for mortars using the Level Based Weight Assessment (LBWA) LBWA–MABAC model. Pamučar *et al.* [24] investigated circular economy concepts in urban mobility alternatives using the integrated DIBR method and the fuzzy Dombi CoCoSo model. Tešić *et al.* [25] proposed a method for defining ranking relationships of fuzzy numbers. Nila *et al.* [26] applied fuzzy logic to decision-making in the design and analysis of drone-based urban logistics solutions for Kochi. Moskolai *et al.* [27] integrated fuzzy decision-making approaches to improve the quality of urban mobility services in developing countries. Eti & Yüksel [28] integrated Pythagorean fuzzy Simple Additive Weighting (fuzzy SAW) and Entropy methods for decision-making regarding legal efficiency in renewable energy projects. Dağistanlı [29] selected weapon systems for defense planning using Lanchester models integrated with fuzzy logic in a computer-assisted military experiment. Božanić *et al.* [30] proposed a fuzzy DIBR II–MABAC model for flood prevention in a case study of the Veliki Rzav River. Ayvaz *et al.* [31] developed an integrated Fine–Kinney risk assessment model based on Fermatean fuzzy AHP–WASPAS for occupational hazards in the aquaculture sector. Ali *et al.* [32] evaluated risk priorities in a core preparation experiment using fuzzy VIKOR integrated with Shannon entropy. Biswas *et al.* [33] proposed a neutrosophic fuzzy decision-making framework for location selection. Žnidaršič *et al.* [34] applied a DIBR–TOPSIS model to select river crossing locations for assault boats. Finally, Božanić *et al.* [35] applied the fuzzy DIBR II–MABAC model to rank construction machines, among many other applications.

On the other hand, to the best of the authors' knowledge, no previous study has addressed the problem of improving the effectiveness of indirect fire with an automatic grenade launcher against targets located on reverse slopes, despite the fact that this weapon system has been in military service for more than two decades.

1.1 Role and Employment of the Automatic Grenade Launcher in Combat Operations

In Rulebook for the 30 mm M93 Automatic Grenade Launcher [5] the Automatic Grenade Launcher (AGL) is an infantry support weapon designed to neutralize and destroy personnel and fire support assets at ranges of up to 1730 m. An AGL squad is assigned to the support platoon of an infantry company and consists of three weapons, each operated by a three-member crew. The weapon combines the characteristics of a machine gun and a mortar and is capable of firing using both the lower and upper groups of firing angles, i.e., direct and semi-direct fire from 0° to 45°, and high-angle fire from 45° to 70°. The total weight of the weapon is approximately 35 kg and consists

of the launcher, tripod, sighting device, a drum magazine containing 30 links with 29 grenades, and a set of spare parts, tools, and accessories. The grenade is equipped with a self-destruct mechanism that activates after 26 seconds if the grenade fails to detonate upon impact due to a shallow angle of impact. The grenade has a muzzle velocity of 185 m/s, with a complete cartridge weighing 355 g and the grenade itself weighing 270 g. The basic combat load consists of 174 grenades. The AGL is capable of automatic fire. At the minimum practical rate of fire, one grenade is fired every two seconds, corresponding to 30 (approximately 29 loaded grenades) per minute—the capacity of one ammunition belt. At the maximum practical rate of fire, the weapon can fire approximately 60 grenades per minute, depending on the proficiency of the crew. This weapon can be regarded as a system capable of delivering the effect of a hand grenade at distances of up to 1730 m behind obstacles while engaging targets on reverse slopes from concealed positions such as depressions and ravines, where the crew remains protected. At the same time, it is capable of accurately engaging point-sensitive targets at these ranges using the lower group of firing angles below 45°. The tripod provides a minimum barrel elevation of -5° and a maximum elevation of 70° . The weapon manual also defines the procedure for determining the minimum firing distance when the weapon is positioned behind an obstacle.

According to the tactical principles governing its employment, the automatic grenade launcher squad should form part of the company fire support group together with 82 mm mortars, whose maximum range is approximately 4500 m, although the two weapon systems differ significantly in their operational characteristics. Ideally, the AGL would complement a 60 mm mortar, which is generally available only in special forces units rather than regular infantry units. Consequently, the grenade launcher squad can often be employed more effectively either independently or by distributing individual weapon crews. During combat operations, when operating within an infantry company, the support platoon forms a temporary company fire support group. At the company commander's discretion, either a single weapon or the entire grenade launcher squad may be attached to another unit, such as a rifle platoon, or the squad may be dispersed among rifle squads operating on directions where the weapons can achieve the greatest effect against expected targets. During combat operations, the company fire support group constitutes an element of the infantry company's combat formation. A combat formation represents the most appropriate deployment of forces and assets on the terrain for accomplishing a specific mission. The combat formation of the company fire support group consists of an observation post, a fire position, and the location of transport vehicles.

Although this paper does not directly address either the fire position or the observation post, it is evident that the selection of a fire position is directly related to the selection of the target area, and one may constrain or even preclude the other. In other words, if a suitable fire position cannot be selected because of terrain characteristics, it may not be possible to engage a target located at a given distance on a reverse slope. This inherent uncertainty justifies the application of fuzzy numbers in the proposed decision-making model.

2. Methodology

The hybrid model applied to solve the problem of selecting the terrain slope in the target area consists of the fuzzy DIBR II–MABAC methods. The fuzzy DIBR II method is used to determine the weighting coefficients of the criteria, while the fuzzy MABAC method is employed to rank the alternatives and select the most favorable one among the four possible alternatives.

Figure 1 presents the framework of the proposed model, whose steps must be carried out consistently in order to obtain a valid solution.

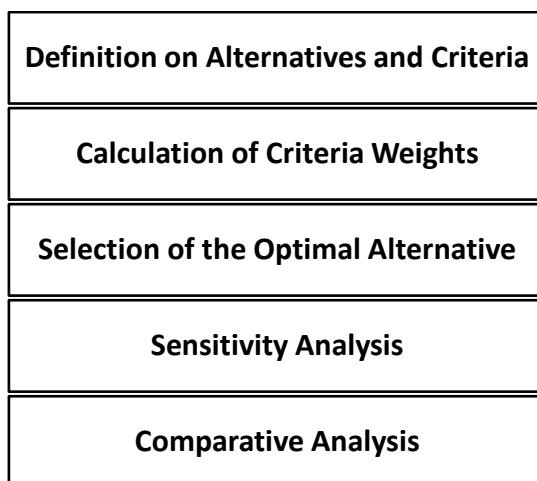


Fig. 1. Model Steps

2.1 Defining Interrelationships Between Ranked Criteria II (DIBR II)

The DIBR II method was developed by Božanić & Pamučar [36]. This method belongs to the group of subjective methods for determining criterion weight coefficients. It was used in several scientific papers [37-38]. The procedure consists of nine steps:

Step 1: Defining criteria. A set of criteria $S = \{C_1, C_2, \dots, C_n\}$ is defined for comparing alternatives. The criteria may be qualitative or quantitative, i.e., numerical or linguistic.

Step 2: Ranking the criteria by importance. The criteria are ranked from most to least significant, represented as $C_1 > C_2 > C_3, \dots, > C_n$. The ranking is performed by experts in the relevant field.

Step 3: Defining the importance relationship between adjacent criteria. The step consists of two parts. First, adjacent criteria are performed using the following expression:

$$\frac{w_1}{w_2} = d_{1,2} \quad (1)$$

$$\frac{w_2}{w_3} = d_{2,3} \quad (2)$$

...

$$\frac{w_{n-1}}{w_n} = d_{n-1,n} \quad (3)$$

where $d_{1,2}, d_{2,3}, \dots, d_{n-1,n}$ represents the significance ratio of neighboring criteria.

The second part defines the importance ratio between the most and least significant criteria, serving as a control factor for evaluating the consistency of the assessments.

$$\frac{w_1}{w_n} = d_{1,n} \quad (4)$$

Step 4: Calculation of the ratio between the most significant and other criteria. Based on expressions (1)-(3), the weights of the other criteria are expressed in relation to the most significant one:

$$w_2 = \frac{w_1}{d_{1,2}} \quad (5)$$

$$w_3 = \frac{w_2}{d_{2,3}} = \frac{w_1}{(d_{1,2} * d_{2,3})} \quad (6)$$

...

$$w_n = \frac{w_1}{(d_{1,2} * d_{2,3} * \dots * d_{n-1,n})} \quad (7)$$

Step 5: Calculation of the most significant criterion's weight. Using expressions (5)-(7), the weight of the most significant criterion is calculated as follows:

$$w_1 = \frac{1}{\left[1 + \frac{1}{d_{1,2}} + \frac{1}{(d_{1,2} * d_{2,3})} + \frac{1}{(d_{1,2} * d_{2,3} * \dots * d_{n-1,n})}\right]} \quad (8)$$

Step 6: Calculation of the remaining weight coefficients. The remaining weights $w_1, w_2, \dots, w_n$ are calculated using expressions (5)-(7).

Step 7: Evaluation of the consistency of adjacent criteria relationships. This step aims to minimize subjectivity in the ranking process. The consistency of the defined importance ratios is verified by comparing the ratio between the most and least significant criteria.

$$w_n^c = \frac{w_1}{d_{1,n}} \quad (9)$$

where w_n^c it represents the control weight coefficient of criterion C_n .

Step 8: Verification of the consistency condition. The values of w_n and w_n^c should be approximately equal. If the deviation is less than 10%, the importance ratios are considered consistent. The deviation is calculated as:

$$D_n = \left|1 - \frac{w_n}{w_n^c}\right| \quad (10)$$

where d_n denotes the deviation value of the weighting coefficient for criterion C_n .

Step 9: Validation of the comparison. To ensure the reliability of the comparison, the following condition must be satisfied: $0 \leq D_n \leq 0.1$. If $D_n > 0.1$, the relationship between the criteria must be redefined.

2.2 Fuzzy sets

A real number has a unique crisp value. In cases of unclear or complex phenomena, a problem arises when the decision maker is not entirely sure the value is 100% correct. In classical set theory, the membership of elements in a set is evaluated in a binary sense, according to a bivalent condition - an element either belongs to a set or it does not, by Chatterjee & Stević [39]. However, it is not always possible to make such a clear distinction, especially in the case of complex phenomena that cannot be easily described by traditional mathematical methods, particularly when the goal is to find an approximately good solution - Bojadziev & Bojadziev [40]. Modeling using fuzzy sets has proven to be an effective way of formulating decision-making problems in situations where the available input information is subjective or imprecise by Zimmermann [41]. Fuzzy sets are sets whose elements have degrees of membership. Fuzzy set theory was first introduced by Zadeh [42], whose approach enables decision-makers to deal with uncertainty effectively. Fuzzy sets are most commonly represented by triangular - triangle's fuzzy number (TFN), trapezoidal, and Gaussian fuzzy numbers. In this paper, triangular fuzzy numbers were used, which can be written as $\tilde{A} = (l, m, r)$.

An important concept in the application of fuzzy numbers is defuzzification, which converts a fuzzy number into a real (crisp) number. Several defuzzification methods can be found in the literature. The most widely used method is the centroid method, also known as the center of gravity or Kwong's method by Kwong & Bai [43]. The TFN $\tilde{A} = (l, m, r)$ is translated into a real, so-called crisp number, using the following expression:

$$defA = \frac{(l + 4 * m + r)}{6} \quad (11)$$

In this way, the fuzzy number is converted back into a real number, which makes it easier to follow, analyze relationships, and perform mathematical operations while retaining the necessary information for comparison and ranking.

2.3 Fuzzy Multi-Attributive Border Approximation Area Comparison (MABAC) method

MABAC and the fuzzy MABAC method provide stable (consistent) solutions and are reliable tools for rational decision-making by Pamučar & Ćirović [44]. This method is a very useful and reliable tool for decision-making across various areas of human activity. So far, it has been used by a large number of authors, either independently or most often in combination with another method. In their book, Alinezhad & Khalili [45] discuss the MABAC method, among others. Sun *et al.* [46] determined the priority of patient care using the MABAC method. Using a modified rough AHP-MABAC method, Sharma *et al.* [47] prioritized stations in Indian Railways. Wang *et al.* [48], combines the MABAC method with fuzzy set q-ROFS. Liang *et al.* [49] use the MABAC method in risk assessment. Luo & Wei-zhang [50] selected the optimal route for new lines in road and rail traffic. Mishra *et al.* [51] select a programming language using the MABAC method. Sahoo & Debnath [52] make a place selection for regenerative tourism practices. A detailed presentation of the fuzzy MABAC method using triangular fuzzy numbers can be found in Božanić *et al.* [53].

2.4 Alternatives and Criteria

In the first phase of the fuzzy model, the criteria that directly influence the selection of the best alternative, i.e., the optimal target area, which is directly related to the fire position, were defined. Defining the criteria and their weighting coefficients represents an important phase in decision-making models by Pamučar *et al.* [54]. Due to the complexity of the problem, experts were engaged to define the selection criteria. Based on the applicable operating procedures for the weapon system and expert opinions, six criteria, denoted as C_1 to C_6 , were identified for the considered problem.

According to Manual for Tactical Training [55] and in Rulebook for the 30 mm M93 Automatic Grenade Launcher [5], four alternatives were defined, representing possible locations with a certain terrain slope where a target may appear and where the grenade can achieve its effect. Depending on that location, it is necessary to select a firing position from which the grenade launcher can hit that area in accordance with its specific characteristics. It is assumed that the target area is located behind a natural or artificial obstacle so that the crew is protected from observation and enemy fire, while at the same time not having visual contact with the opponent.

A_1 – Flat terrain with a slope of up to 5%. On this terrain, the target can move the fastest and easily change its positions. On the other hand, observation and projectile guidance are easier, and the projectile impact angle corresponds to the conditions prescribed in the regulations.

A_2 – Slightly steep terrain with a slope between 5% and 10%. On this terrain, the target moves more slowly compared to the previous one but is forced to move in a more bent posture rather than upright. Projectile observation is favorable, while the projectile impact angle depends on the side of the slope. According to the principles, this would also be a probable area where the target may appear.

A_3 – Steep terrain with a slope between 10% and 20%. On this terrain, the target moves even more slowly compared to the previous one and moves in a bent posture. Projectile observation is favorable depending on the type of soil and terrain cover. This would also be a probable area where the target may appear, as it would avoid both flat terrain and very steep terrain.

A₄ – Very steep terrain with a slope exceeding 20%. On this terrain, the target moves the slowest compared to the previous alternatives and is forced to make frequent stops and rests. This would be the least probable area where the target may appear due to the excessive fatigue imposed on personnel and equipment. However, past experience has shown that, in pursuit of success and surprise, the opponent often chooses the most difficult option even though it is the least favorable.

The selection of the most favorable target area is based on the following six criteria:

C₁ – *Target movement pattern*. This criterion is of the benefit type and is expressed linguistically. The target may move either upright or in a crouched posture. Since the area target is located behind an obstacle, where no engagement is expected until it approaches to establish combat contact, it is assumed that the target will be moving on foot without the use of vehicles. The movement pattern is directly related to criteria C₄ and C₅, as movement depends on terrain cover, soil type, and terrain slope. A steeper slope, denser vegetation, and softer soil result in slower and crouched movement, whereas the opposite conditions favor upright movement. Crawling is also possible but is considered unlikely because of the distance involved and the absence of visual contact. Upright movement provides a greater fragmentation effect of the grenade on the target and is therefore more favorable for the defender and less favorable for the attacking force, according to Manual for Tactical Training [55], ATP 3-21.50 [56] and Angelidou *et al.* [57]. The influence of terrain characteristics on vehicle mobility has been analyzed by Potić & Đorđević [58], and similar considerations can also be applied to dismounted infantry movement.

C₂ – *Distance to the target*, expressed in meters. This is a cost-type criterion. Ideally, the fire position is generally established at one-third of the weapon's maximum range from the target during offensive operations and at two-thirds of the maximum range during defensive operations, with the weapon having a maximum range of 1730 m. Since the fire position is concealed behind a natural obstacle on the reverse slope, there is no visual contact between the weapon and the target. A specific characteristic of the automatic grenade launcher when firing with a high-angle trajectory (upper group of firing angles) is that its minimum firing distance is 1000 m, corresponding to the maximum barrel elevation of 70°. The distance to the target is directly related to the possibility of selecting both the fire position and the target area according to terrain configuration, and it also determines the projectile's flight time. Greater distances result in a flight time that is several seconds longer and in increased projectile dispersion, which is less favorable for friendly forces and more favorable for the enemy. This criterion is divided into a shorter distance (1000–1400 m) and a longer distance (1400–1730 m), according to Rulebook for the 30 mm M93 Automatic Grenade Launcher [5].

C₃ – *Grenade flight time*, expressed in seconds. This is a cost-type criterion. The values are taken from the weapon manual and range from 21.5 s at a distance of 1000 m to 27 s at the maximum range of 1730 m. A shorter flight time is preferable because it provides the target with less time to react, according to Rulebook for the 30 mm M93 Automatic Grenade Launcher [5].

C₄ – *Terrain cover in the target area*. This criterion describes terrain characteristics that influence both target movement and the effectiveness of the projectile. It is a cost-type linguistic criterion. The denser the vegetation, the slower the target movement, but also the lower the effectiveness of the grenade against the target. If vegetation exceeds 1 m in height, the projectile's effectiveness is significantly reduced, and the use of the automatic grenade launcher is therefore not recommended. With respect to terrain cover, the terrain may be classified as open when vegetation is up to 0.5 m high and covered when vegetation ranges from 0.5 m to 1 m in height, according to ATP 3-21.8 [59].

C₅ – *Soil type*. This criterion represents a terrain characteristic in the target area that influences target movement, projectile effectiveness, and the target's concealment. It is a benefit-type linguistic criterion. The soil may be either soft or hard. The greatest grenade effectiveness is achieved on rocky

or hard ground because, upon detonation, fragments of both the grenade casing and the surrounding rocks increase the fragmentation effect and inflict additional damage on the target. At the same time, movement across such terrain is slower and the target is more exposed. On soft ground, the grenade penetrates the soil before detonation, causing many fragments to remain embedded in the ground, which reduces the fragmentation effect and is therefore more favorable for the enemy, according to ATP 3-21.8 [59].

C_6 – *Type of area target*. Although engagement of an individual target is possible, it is excluded from consideration in this study. Since the target is located behind an obstacle at a minimum distance of 1 km from the weapon, an area target is assumed. This is a benefit-type linguistic criterion. The larger the target group or crew, the greater the grenade's effectiveness. A typical target for the automatic grenade launcher is the crew of a weapon system or a group of riflemen. The area target may therefore be either a weapon crew or a squad/team of soldiers, according to Ryzhonkova *et al.* [60].

The set of criteria (C_j) consists of two subsets: the subset of benefit criteria (benefit), denoted by C^+ , for which higher values are preferred, and the subset of cost criteria (cost), denoted by C^- , for which lower values are preferred. In the present case, criteria C_1 , C_5 , and C_6 belong to the benefit, whereas criteria C_2 , C_3 , and C_4 belong to the cost subset.

The values of criteria C_2 and C_3 are expressed numerically, whereas the remaining criteria are linguistic and must be converted into numerical values according to the corresponding conversion tables. The values of criterion C_1 are presented using a linguistic scale, as shown in Table 1.

Table 1

Fuzzy linguistic descriptors for criteria C_1

Linguistic condition	fuzzy number
Upright (Up)	(3, 4, 5)
Crouche (Cro)	(2, 3, 4)
Crawling (Cra)	(0.5, 1, 1.5)

On flat terrain, upright movement of the target is expected. If the target is moving upright, there is a higher probability that it will be hit by a grenade fragment. The steeper the terrain, i.e., the greater the slope in the target area, the more crouched the target's movement will be. Since the target does not expect to be engaged and is located behind an obstacle, crawling movement is excluded from consideration.

The values of criterion C_4 are presented using a linguistic scale, as shown in Table 2.

Table 2

Fuzzy linguistic descriptors for criteria C_4

Linguistic condition	fuzzy number
Open (Op)	(1, 2, 3)
Low vegetation (LV)	(2, 3, 4)
High vegetation (HV)	(4, 5, 6)

On open terrain, it is easier to detect and observe hits on the target, and the effect of grenade impact is also maximal. Open terrain is defined as vegetation not higher than 0.5 m, which provides weak protection and concealment. Low vegetation is considered to be vegetation up to 1 m in height, which provides a higher degree of protection for the target, and if the target is moving in a crouched posture, it may not be observed. On the other hand, the effect of grenade impact is reduced because vegetation retains grenade fragments.

The values of criterion C_5 are presented using a linguistic scale, as shown in Table 3.

Table 3

Fuzzy linguistic descriptors for criteria C_5

Linguistic condition	fuzzy number
Soft soil (So)	(2, 3, 4)
Medium hard (MH)	(3, 4, 5)
Very hard (VH)	(4, 5, 6)

Soft soil is considered waterlogged, marshy terrain on which the target moves slowly; however, the grenade also penetrates into the ground, which retains fragments and reduces the fragmentation effect. Medium-hard soil (MH) is considered to be normal terrain. Very hard soil (VH) refers to rocky or stony terrain, where the target moves slowly, while the effect of the grenade is maximal.

The values of criterion C_6 are presented using a linguistic scale, as shown in Table 4.

Table 4

Fuzzy linguistic descriptors for criteria C_6

Linguistic condition	fuzzy number
Individual (In)	(0.5, 1, 1.5)
Crew (Cr)	(1, 2, 3)
Squad/Team (ST)	(2, 3, 4)

The larger the number of soldiers in a crew or team/squad, the higher the probability that a grenade casing fragment will hit the target.

3. Results

The DIBR II–Fuzzy MABAC hybrid model consists of five phases. In the first phase of the fuzzy model, the criteria are defined based on expert judgment. The second phase involves the calculation of the weighting coefficients of the criteria using expert judgment and the DIBR II method. In the third phase, the best alternative is selected using the fuzzy MABAC method. This is followed by the sensitivity analysis of the developed model, rank correlation, and comparative analysis.

3.1 Calculation of Criteria Weighting Coefficients Using the Fuzzy DIBR II Method

Using the fuzzy DIBR II method, the values of the weighting coefficients of the criteria were determined according to expressions (1) to (10), through the defined phases. The first phase has already been completed in the previous description, where experts identified six criteria. In the first step, based on a questionnaire, decision-makers selected six criteria that influence the target engagement from behind an obstacle.

After defining the criteria, in the second step, the experts performed the ranking of the criteria as follows:

$$C_1 > C_6 > C_5 > C_4 > C_2 > C_3$$

In addition, the experts defined that the ratio between the most important criterion C_1 and the least important criterion C_3 is 3. ($\frac{C_1}{C_3} = 3$). Based on this, a linguistic condition was formed, which simplifies the DIBR II method because it defines the relationships between the weights of adjacent criteria, thereby reducing the number of required steps.

Table 5

Fuzzy linguistic descriptors for ranking of criteria

Linguistic condition	fuzzy number
Most significant	(0.263,0.273,0.283)
Very highly significant	(0.218,0.228,0.238)
Highly significant	(0.165,0.175,0.185)
Moderately significant	(0.115,0.125,0.135)
Low significance	(0.094,0.104,0.114)
Least significant	(0.085,0.095,0.105)

Based on Table 5, the weighting coefficients of the criteria were determined and are presented in Table 6.

Table 6

Criteria weights represented as fuzzy numbers

Weighting coefficient	Fuzzy number
W_1	0.263,0.273,0.283
W_6	0.218,0.228,0.238
W_5	0.165,0.175,0.185
W_4	0.115,0.125,0.135
W_2	0.094,0.104,0.114
W_3	0.085,0.095,0.105

By applying expression (11), the fuzzy numbers were defuzzified, resulting in the weighting coefficients of the criteria expressed as real (crisp) numbers, which are presented in Table 7.

Table 7

Criteria weighting coefficients obtained by the Fuzzy DIBR II method

	C_1	C_2	C_3	C_4	C_5	C_6
W	0.273	0.104	0.095	0.125	0.175	0.228

In the seventh step, the evaluation of the quality of the defined importance of the criteria is performed based on the weighting coefficient of the most significant criterion w_1 and the value of the importance ratio between the most significant and the least significant criterion using expression (9):

$$w_6^c = \frac{w_1}{d_{1,6}} = \frac{0.273}{3} = 0.091$$

The deviation check is carried out using formula (10):

$$d_6 = 1 - \frac{0.091}{0.095} = 0.042$$

From the obtained deviation value of the weighting coefficients between the most significant criterion C_1 and the least significant criterion C_3 , it can be concluded that the condition $0 \leq d \leq 0.1$ is satisfied, i.e., the deviation is within the permissible range of up to 10%, specifically 4.2% in this case. After determining the weighting coefficients of the criteria, it is possible to proceed to the next phase of the model.

3.2 Selection of the Best Alternative Using the Fuzzy MABAC Method

The third phase of the model involves the selection of the best alternative for the target area using the fuzzy MABAC method, as previously described. Four potential locations (alternatives) for the target area behind a natural obstacle were considered in the study. The characteristics were

defined according to the terrain slope in the target area, ranging from the least steep, i.e., flat terrain, to the most steep terrain with slopes exceeding 40°.

The first step is the construction of the initial decision matrix – Tables 8 and 9. Table 8 presents the initial decision matrix. For the considered alternatives, numerical and linguistic values are assigned according to the defined criteria.

Table 8

The initial decision matrix

	C₁ (ben)	C₂ (cost)	C₃ (cost)	C₄ (cost)	C₅ (ben)	C₆ (ben)
A ₁	Up	1.4,1.55,1.73	26.4,26.7,27	LV	So	Cr
A ₂	Cro	1.4,1.55,1.73	26.4,26.7,27	Op	Vh	ST
A ₃	Up	1,1.2,1.4	21.5,22,22.5	Op	Mh	Cr
A ₄	Cro	1,1.2,1.4	21.5,22,22.5	LV	So	ST

The linguistic values in Table 8 are quantified into numerical values. After quantification, the criteria are presented as triangular fuzzy numbers in Table 9.

Table 9

Quantification of the Initial Decision Matrix

	C₁ (ben)	C₂ (cost)	C₃ (cost)	C₄ (cost)	C₅ (ben)	C₆ (ben)
A ₁	3,4,5	1.4,1.55,1.73	26.4,26.7,27	2,3,4	2,3,4	1,2,3
A ₂	2,3,4	1.4,1.55,1.73	26.4,26.7,27	1,2,3	4,5,6	2,3,4
A ₃	3,4,5	1,1.2,1.4	21.5,22,22.5	1,2,3	3,4,5	1,2,3
A ₄	2,3,4	1,1.2,1.4	21.5,22,22.5	2,3,4	2,3,4	2,3,4

For certain criteria, the experts did not take specific values into consideration. For C₁, the target moving by crawling was not taken into account because it was concealed. For C₄, terrain covered with tall vegetation was not taken into account because firing would be impossible due to the inability to observe the target. For C₆, engaging an individual target was not taken into consideration because it is unprofitable and uneconomical for the support weapon.

The normalization of the elements from the quantified initial decision matrix, as shown in Table 10.

Table 10

Normalized decision matrix

	C₁ (ben)	C₂ (cost)	C₃ (cost)	C₄ (cost)	C₅ (ben)	C₆ (ben)
A ₁	0.333,0.667,1	0,0.247,0.452	0,0.55,0.122	0,0.333,0.667	0,0.25,0.5	0,0.333,0.667
A ₂	0,0.333,0.667	0,0.247,0.452	0,0.55,0.122	0.333,0.667,1	0.5,0.75,1	0.333,0.667,1
A ₃	0.333,0.667,1	0.422,0.726,1	1.154,0.909,1.122	0.333,0.667,1	0.25,0.5,0.75	0,0.333,0.667
A ₄	0,0.333,0.667	0.422,0.726,1	1.154,0.909,1.122	0,0.333,0.667	0,0.25,0.5	0.333,0.667,1

The elements of the weighted matrix (V), as presented in Table 11.

Table 11

Weighted normalized matrix

GAO	C ₁ (ben)	C ₂ (cost)	C ₃ (cost)	C ₄ (cost)	C ₅ (ben)	C ₆ (ben)
A ₁	0.363,0.453,0.544	0.104,0.13,0.151	0.096,0.101,0.108	0.125,0.167,0.208	0.175,0.219,0.263	0.228,0.304,0.38
A ₂	0.272,0.363,0.453	0.104,0.13,0.151	0.096,0.101,0.108	0.167,0.208,0.25	0.263,0.306,0.35	0.304,0.38,0.456
A ₃	0.363,0.453,0.544	0.151,0.18,0.208	0.207,0.183,0.204	0.167,0.208,0.25	0.219,0.263,0.306	0.228,0.304,0.38
A ₄	0.272,0.363,0.453	0.151,0.18,0.208	0.207,0.183,0.204	0.125,0.167,0.208	0.175,0.219,0.263	0.304,0.38,0.456

The border approximation area, as presented in Table 12.

Table 12

Border approximation area matrix

C ₁ (ben)	C ₂ (cost)	C ₃ (cost)	C ₄ (cost)	C ₅ (ben)	C ₆ (ben)
0.314,0.405,0.497	0.125,0.153,0.177	0.141,0.136,0.148	0.144,0.186,0.228	0.205,0.249,0.293	0.263,0.34,0.416

The distances of the alternatives from the Boundary Approximation Area (BAA), as shown in Table 13

Table 13

Matrix of the Distances of the Alternatives from the Boundary Approximation Area

GAO	C ₁ (ben)	C ₂ (cost)	...	C ₆ (ben)
A ₁	-0.134,0.048,0.230	-0.073,-0.023,0.026		-0.0188,-0.036,0.117
A ₂	-0.225,-0.043,0.139	-0.073,-0.023,0.026		-0.112,0.04,0.193
A ₃	-0.134,0.048,0.230	-0.026,0.027,0.083	...	-0.0188,-0.036,0.117
A ₄	-0.225,-0.043,0.139	-0.026,0.027,0.083		-0.112,0.04,0.193

The triangular fuzzy numbers were converted into crisp values by applying equation (11) in order to determine the final ranking of the alternatives. The final values of the alternatives' criterion functions were obtained by summing the elements of matrix Q across the rows, as presented in Table 14.

Table 14

Ranking of the Alternatives Using the Fuzzy MABAC Method

A	Si	Q _j	Rank
A ₁	-0.669,-0.096,0.461	-0,0986	4
A ₂	-0.554,0.019,0.575	0,01591	3
A ₃	0.426,0.121,0.699	0,12655	1
A ₄	-0.526,0.021,0.599	0,02647	2

Based on the obtained results, it can be concluded that alternative A₃ is ranked first. Accordingly, the ranking of the alternatives is as follows: A₃, A₄, A₂, and A₁.

3.3 Sensitivity Analysis

The fourth phase involves conducting a sensitivity analysis of the proposed model to provide the decision-maker with confirmation of the quality of the obtained solution and to determine how changes in the criterion weights affect the ranking of the alternatives by Tešić *et al.* [61]. Verifying the stability of the applied multi-criteria decision-making methods is an essential step in the development of decision-support models by Božanić *et al.* [62]. The stability analysis was performed by gradually reducing the weight of the most significant criterion, W₁ (0.272), by 5% increments, up to a total reduction of 95% (0.136), across 19 scenarios, with the reduced weight being equally

redistributed among the remaining criteria. The ranking of the alternatives for each scenario is presented in Table 15.

Table 15
Ranking of the Alternatives Across Scenarios with Reduced W_1

Sc	A ₁	A ₂	A ₃	A ₄
Sc1	4	3	1	2
Sc2	4	3	1	2
		.		
		.		
		.		
Sc19	4	3	1	2

Based on Table 15, it can be observed that the model maintains its stability despite changes in the weight coefficient of the most important criterion, preserving the ranking of the alternatives throughout all scenarios.

Since none of the alternatives changes its ranking across the analyzed scenarios, the Spearman rank correlation coefficient equals 1, indicating a perfect correlation, according to the following expression:

$$S = 1 - \frac{6 \sum_{i=1}^n D_i^2}{n(n^2 - 1)} \quad (12)$$

where D_i denotes the difference between the rank of an alternative in the initial ranking i_n and its rank in the corresponding scenario, while n represents the number of ranked alternatives.

The Spearman rank correlation coefficient takes values within the interval $(-1,1)$ by Radovanović *et al.* [63]. When the rankings of the alternatives are identical, the Spearman coefficient equals 1, indicating a perfect positive correlation. Conversely, when the rankings are completely reversed, the coefficient equals -1 , indicating a perfect negative correlation. A value of $S = 0$ indicates that the rankings are uncorrelated.

It can be concluded that the Spearman rank correlation coefficients obtained for all values of W are exceptionally high, indicating a perfect positive correlation between the rankings. No deviation from the perfect positive correlation, nor any indication of negative correlation, was observed. Based on these results, it can be concluded that the proposed model demonstrates satisfactory sensitivity.

3.4 Comparative Analysis

The comparative analysis was performed in two ways. In the first approach, the determined criterion weights were applied to the classical SAW - more details can be found in Churchman & Ackoff [64], TOPSIS - more details can be found in Hwang & Yoon [65], MABAC, and Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA) - more details can be found in Gigović *et al.* [66], methods, using the defuzzified (crisp) values of the fuzzy numbers, i.e., their mean values. In this way, the rankings of the alternatives were obtained, as presented in Figure 2.

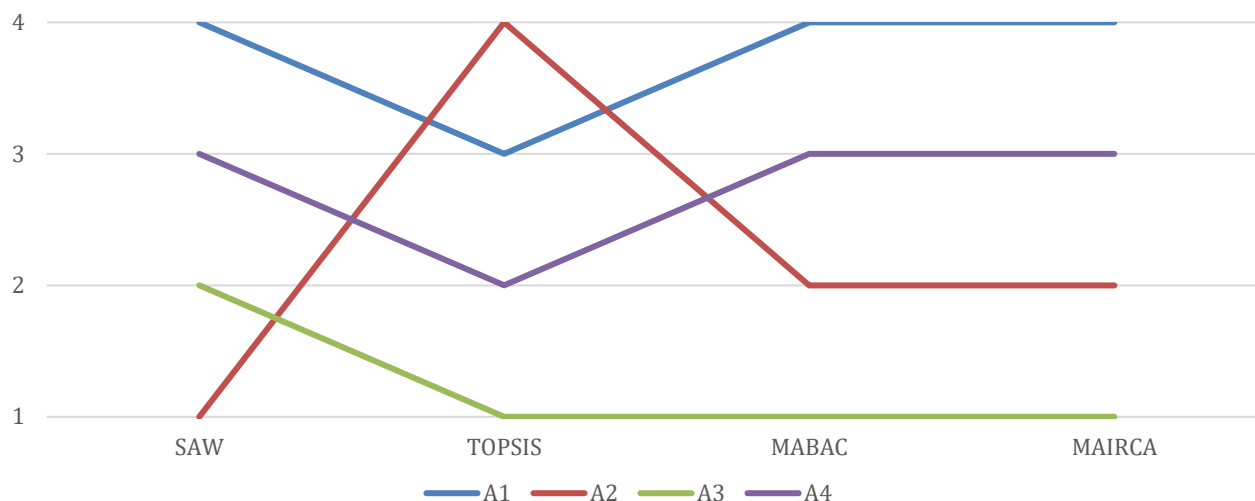


Fig. 2. Ranking of the Alternatives According to the SAW, TOPSIS, MABAC, and MAIRCA Methods

From the presented results, it can be concluded that alternative A_3 is ranked first across all methods except the SAW method, where it is ranked second. According to the SAW method, alternative A_2 is ranked first, while the same alternative is ranked last according to the TOPSIS method.

The Spearman rank correlation coefficient is presented in Figure 3. It indicates a very low correlation of 0.4 for the SAW method, while the other methods show a very high correlation of 0.8 between the rankings.

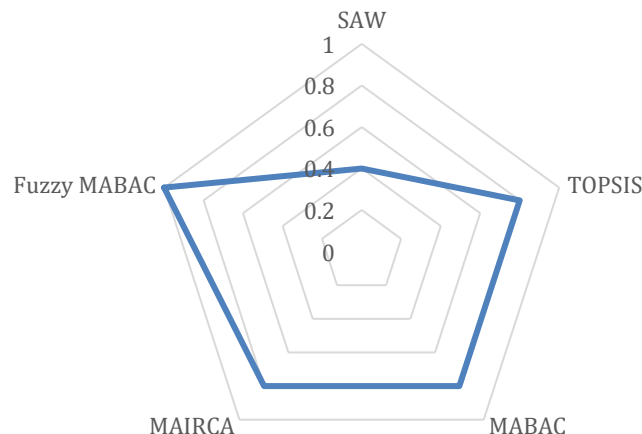


Fig. 3. Spearman Rank Correlation Coefficient of SAW, TOPSIS, MABAC, and MAIRCA Methods in Relation to the Fuzzy MABAC Method

The second comparative analysis was performed in a unified manner. Since four alternatives were considered and the experts identified the most probable criteria, the values of criteria C_1 , C_4 , C_5 , and C_6 were modified, and for each rotation of criterion values, the rankings of the alternatives were determined.

This approach is justified by the fact that, for criterion C_1 , the target can move across different types of terrain in three ways. Although it was previously noted that movement by crawling is unlikely

and movement on very steep terrain is restricted, when a steep slope is considered, the target always moves in a tilted posture relative to the terrain and cannot move upright.

A similar rationale applies to criteria C_4 (terrain coverage) and C_5 (soil type). These criteria are directly dependent and mutually exclusive. Specifically, in densely vegetated terrain, the target must move upright in order to maintain visibility, whereas in open terrain it moves differently. For criterion C_6 , there is a low probability that a larger group or unit moves in open terrain.

The ranking of alternatives is presented in Figure 4, according to the variations of criteria based on expert judgments.

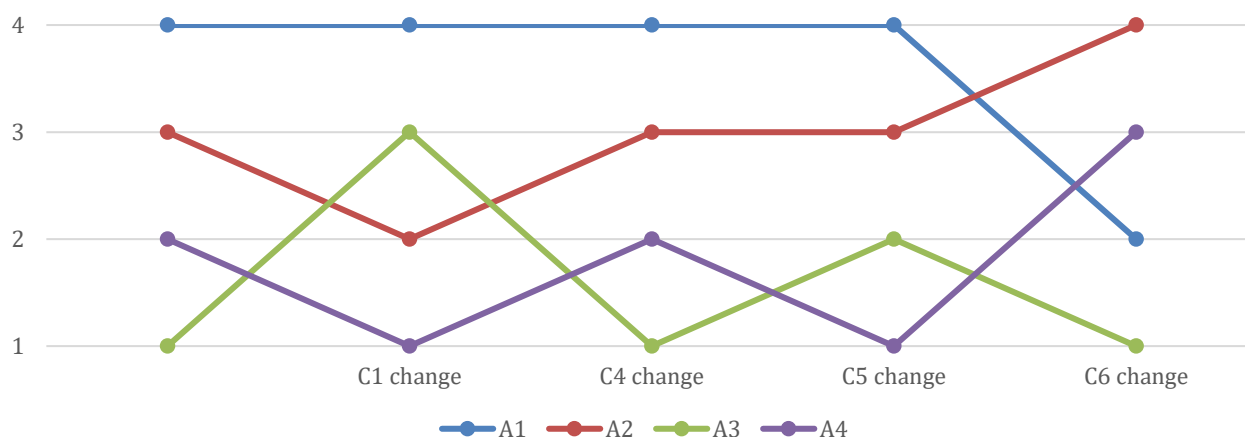


Fig. 4. Ranking of the Alternatives under Changes in Criteria C_1 , C_4 , C_5 , and C_6

When the value of the most important criterion, C_1 , is changed, a sudden shift in the rankings occurs, where alternative A_1 becomes the best-ranked, while A_4 is ranked first in some scenarios and third in others. The remaining alternatives maintain a sufficient level of stability.

In the overall ranking, it can be concluded that A_3 is ranked first in 60% of the cases (three times), while A_4 is ranked first in 40% of the cases (two times). This indicates that the most appropriate choice of the system is when the target is located on steep or very steep terrain.

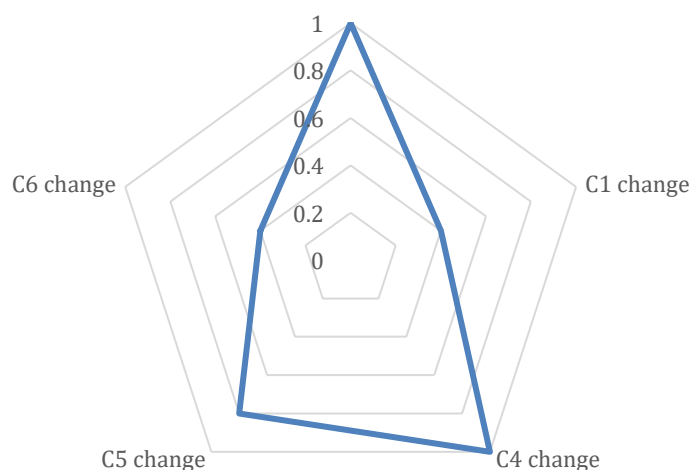


Fig. 5. Spearman Rank Correlation Coefficient of the Alternatives under Changes in Criteria C_1 , C_4 , C_5 and C_6

The Spearman rank correlation coefficient under changes in coefficients C_1 and C_6 shows a very low correlation of 0.4, since these are criteria with high weights and thus have a significant influence

on the ranking of alternatives. In contrast, when the positions of criteria C_4 and C_5 are changed, the ranking remains stable, with very high and high correlation values, respectively.

3. Conclusion

This paper presents a hybrid fuzzy multi-criteria decision-making model based on the fuzzy DIBR II and fuzzy MABAC methods for selecting the optimal position under uncertain conditions. The proposed approach addresses the problem of determining the most suitable target area where the projectile can achieve the maximum effect.

The results obtained using the fuzzy MABAC method indicate that alternative A_3 is the most favorable, while A_1 represents the least suitable option. Sensitivity and comparative analyses confirmed the stability and reliability of the proposed model, demonstrating that the ranking of alternatives remains consistent under different conditions.

The main contribution of this research is the development of a simple, reliable, and applicable decision-support model for solving complex problems in military sciences. The integration of fuzzy DIBR II and MABAC enables experts to incorporate uncertainty and subjective judgments into the decision-making process while maintaining model robustness.

Future research should focus on applying the proposed model to other military and social decision-making problems, as well as investigating its potential integration with alternative multi-criteria methods under different operational conditions.

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