Operational Research in Engineering Sciences: Theory and Applications
Vol. 4, Issue 1, 2021, pp. 115-135
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta20401156j

SELECTION OF FIRE POSITION OF MORTAR UNITS USING LBWA AND FUZZY MABAC MODEL

Željko Jokić*, Darko Božanić, Dragan Pamučar

Military Academy, University of Defence in Belgrade, Serbia

Received: 18 February 2021
Accepted: 26 March 2021
First online: 28 March 2021

Original scientific paper

***Abstract**: The paper presents a hybrid model based on the LBWA method and the fuzzy MABAC method, applied when selecting firing positions' locations of the Serbian Army's mortar units. Using a questionnaire, the experts determined the criteria for choosing the firing position. The LBWA method is used to determine the weighting coefficients of the criteria, while the fuzzy MABAC method is used to determine the most favorable location of the firing position by choosing between six specific options - alternatives. By changing the value of the elasticity coefficients, the sensitivity analysis of the developed model was performed, and by applying the Spearman coefficient, it was determined that there is an ideal positive correlation of ranks.*

***Key words**: LBWA, MABAC, fuzzy numbers, mortar units, firing position.*

1. Introduction

The entire twentieth and the beginning of the 21st century were marked by dizzying technological developments that could not but include the military industry. The impact of technological development on armaments and military equipment also conditioned a change in the armed conflicts' physiognomy. Modern combat conflicts are characterized by: sudden and rapid actions of forces from a distance, with mass use of armored and mechanized units and special forces on land, frequent use of helicopter landings, strong air support, and constant possibility and the threat of using weapons of mass destruction.

However, there are means of military equipment which, despite the stated technological development, have not undergone significant changes during all this time, and even without them, no major armed conflict can be imagined. From its appearance in 1904, in the Russo-Japanese War, to the present day, mortars have undergone small changes. They are produced in various calibers, of which the most common are 60 mm, 81-82 mm, and 120 mm, as traction or self-propelled. With the

* Corresponding author.
antras1209@gmail.com (Ž. Jokić), dbozanic@yahoo.com (D. Božanić), dpamucar@gmail.com (D. Pamučar)

possibility of shooting in a vertical path, they are suitable for shooting from bays, ravines, and from the back slope.

Mortar units are the basis of the infantry battalion's fire support in performing all types of combat operations. With their firepower and the possibility of quick maneuver, they can bring an advantage on the field, provided they are used correctly, which, above all, depends on the correct choice of the location of the combat schedule elements.

The article discusses the choice of the location of the battalion fire group fire position (BFG) formed by the company-platoon of 120 mm mortars. The ultimate goal of the article is to apply a model that will support the decision-maker in choosing the location of the firing position, which would significantly reduce the response time and the possibility of making an inadequate decision.

With the relatively newer LBWA method, the weight coefficients of the criteria for the selection of the location of the firing position (FP) will be determined. Experts in the subject area identified eight criteria, based on the applicable rules and instructions, on which the choice of the location of the firing position directly depends. The choice of the specific location of the firing position, between the six options, will be solved by applying the fuzzy MABAC method.

2. The place and role of mortars in contemporary combat actions

The 120 mm mortar is an accompanying infantry weapon, intended for neutralizing and destroying manpower and firepower, creating smoke curtains, blinding observation posts and firing points, illuminating battlefields, opening passages through wire barriers and minefields, and demolishing light fortification barriers at distances of about 6500 m (Military Encyclopedia, 1973). According to the formation of MB 120 mm, mortar companies or platoons are formed, depending on whether it is an infantry or mechanized battalion.

During combat operations, when operating within a battalion, a company-platoon of 120 mm mortars forms a battalion fire group of temporary composition. At the decision of the Commander, the battalion fire group may be attached to another unit or perform tasks for the needs of a higher unit. The tasks of the battalion fire group, during the execution of combat operations, derive from the purpose of the 120 mm mortar (Military Encyclopedia, 1973):

- neutralization and destruction of the enemy's manpower, firepower and fire support,
- fight against enemy landings,
- neutralization of enemy observation posts and observation posts,
- neutralization of enemy command posts and communication centers,
- demolition and destruction of field-type fortifications and opening of passages in obstacles,
- smoking and lighting of certain areas and rooms.

When conducting combat operations, BFG possesses elements of the combat schedule, which is part of the combat schedule of the battalion in which it operates, ie the unit it supports. The combat schedule of the BFG consists of an observation post, a firing position and a place of means of transport. The command part has an observation post, and the fire part has a fire position. Before possessing the stated elements of the combat schedule, the selection of optimal regions-locations for the execution of the obtained task is performed. As the topic of the paper is the choice of the location of the firing position in the future, the paper will not deal with the observation post.

The fire position (FP) is a region on the land where people, tools, ammunition and traction equipment are deployed in order to perform a fire task (Kurtov et al., 2014). According to the purposes, FP can be: basic, reserve, temporary, next and false, while according to the degree of shelter: sheltered, semi-sheltered and discovered (unprotected).

There are no works in the domestic and foreign literature that deal exclusively with the problem of choosing the firing position for mortar units. In addition to the rules and manuals that deal with mortars from the point of view of construction, some authors in works such as *Department of the Army* (2017), Jenzen-Jones (2015), consider mortars from the aspect of their application. The choice of the location of the basic VP for mortar units belongs to the group of location problems, which are considered in the literature in different ways, both by the type of location and by the applied methods. The problem of the location of military facilities was discussed by Karatas et al. (2019). Božanić & Pamučar (2010) select the location of the bridge crossing using Fuzzy logic. Also, Pamučar et al. (2019) select the optimal location for water barriers using the Interval-Valued Fuzzy-Rough Numbers and MAIRCA methods. Sennaroglu & Celebi (2018) use the AHP, PROMETHEE and VIKOR methods to select the location of the military airport. Pamučar et al. (2016) selected the firing position of the brigade artillery group in the defensive operation using a hybrid model fuzzy AHP - TOPSIS and a fabricated Satie scale. Hamurcu & Eren (2019) using multi-criteria decision-making using the AHP and TOPSIS methods select the best motorcycle route in Ankara. Stoilova (2020) using the AHP and SIMUS optimal railway route in case of an emergency. Liang et al. (2020) address the problem of route selection for perishable goods vehicles. Xu et al. (2020) solve a similar problem by multi-criteria analysis. Darbari et al. (2016) using multi-criteria analysis determine the optimal locations for the collection and disposal of recycled electrical equipment. Ortiz-Astorquiza et al. (2018) conduct a comprehensive overview of problems with the location of accommodation facilities. A similar problem is addressed by Küçükaydın & Aras (2020) using the Fuzzy C-means cluster. Contreras & O'Kelly (2019) address the problem of hub location when designing networks in transportation and telecommunications systems. The hybrid model AHP and PROMETHEE, Abdel-Basset et al. (2021) are used to select the location of coastal wind farms. Pan et al. (2021) are conducting a case study on the selection of the most suitable pedestrian overhead bridge location for the installation of elevators in Singapore using an adaptive Bayesian network.

3. Description of the method

The hybrid model, applied when solving the problem of choosing the location of FP mortars, consists of LBWA and fuzzy MABAC method. The LBWA method is used to determine the weight coefficients of the criteria, while the fuzzy MABAC method is used to determine the most favorable location of the mortars position. Figure 1 shows the scheme of the model.

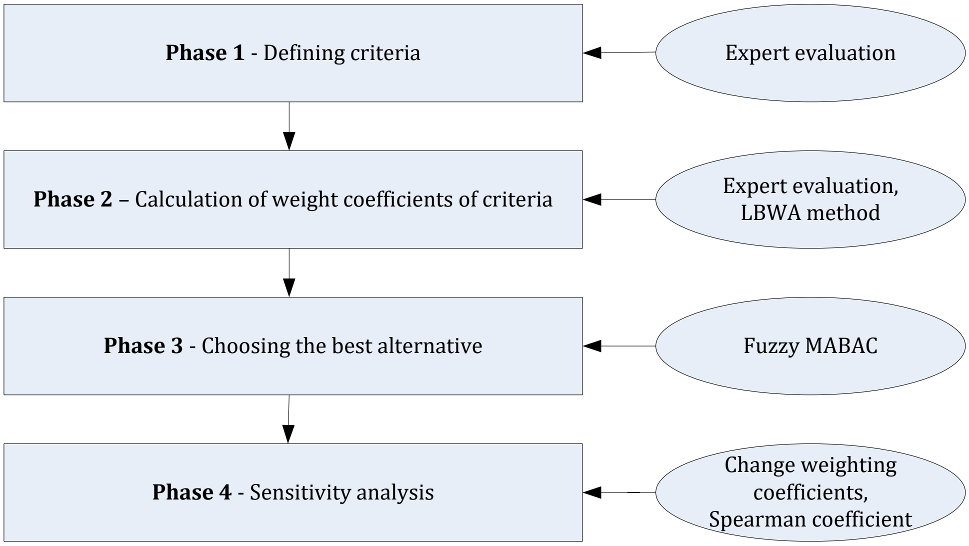

Figure 1. Model scheme

3.1. Level Based Weight Assessment (LBWA) model

The model of weight assessment based on levels (LBWA) was presented for the first time in their work by Žižović & Pamučar in 2019. Although a relatively new method, LBWA has so far been applied in several papers in solving various problems. After the first presentation of the method, Božanić et al. (2020) use a hybrid LBWA - IR-MAIRCA model of multi-criteria decision-making for weapon selection. Fuzzy LBWA – MACBETH – RAFSI was used to develop a multi-criteria model for the sustainable reorganization of the health system in the emergency situation caused by the COVID-19 pandemic (Pamučar et al., 2020b). The choice of the way passengers arrive at the airport in Istanbul was made, also by applying the fuzzy LBWA-WASPAS-H model (Pamučar et al., 2020a).

LBWA is a subjective model for determining weighting coefficients. Advantage of LBWA metod over other is in next keys (Žižović & Pamučar, 2019):

(1) Calculation of weighting coefficients can be realized with a small number of comparison criteria;
(2) A simple algorithm of the LBWA method;
(3) A simple mathematical apparatus is used to obtain the weighting coefficients;
(4) After realized comparisons of criteria, the coefficient of elasticity enables additional corrections of the values of weight coefficient.

Criteria must be defined before applying the LBWA method. If the number of criteria is denoted by *n*, then a set of criteria is available $S = \{C_1, C_2, \ldots, C_n\}$. After that, the LBWA method is approached through the following steps (Žižović & Pamučar, 2019):

Step 1. Determining the most significant criterion. The most important criterion is the one that, in the opinion of experts, has the greatest influence.

Step 2. Grouping the criteria by levels of significance in relation to the most significant criterion, according to the following:

Level S_1*:* From the set *S*, at the level of S_1, criteria are grouped that are of equal importance as C_1 or are up to twice less significant than C_1;

Level S_2*:* From the set *S*, at the level of S_2, the criteria are grouped exactly two times less significant than C_1 or are up to three times less significant than C_1;

Level S_3*: ...*

By applying the previously, the decision-maker is grouping criteria according levels of significance. If the significance of the criteria C_j marks with $s(C_j)$, wherein $j \in \{1, 2, \ldots, n\}$, then we have $S = S_1 \cup S_2 \cup \cdots \cup S_k$, where for each level $i \in \{1, 2, \ldots, k\}$, it is true that it is

$$S_i = \{C_{i_1}, C_{i_2}, \ldots, C_{i_s}\} = \{C_j \in S : i \le s(C_j) < i + 1\} \quad (1)$$

Also, for everyone $p, q \in \{1, 2, \ldots, k\}$ such that it is $p \ne q$ the intersection of the sets is $S_p \cap S_q = \varnothing$.

Step 3. Within the formed subsets, criteria according to significance are compared. Each criterion $C_{i_p} \in S_i$ from the set $S_i = \{C_{i_1}, C_{i_2}, \ldots, C_{i_s}\}$ is assigned an integer $I_{i_p} \in \{0, 1, \ldots, r\}$, that the most important criterion C_1 is assigned a number $I_1 = 0$. If it is C_{i_p} more significant than C_{i_q} than it is $I_p < I_q$, and if it is C_{i_p} of the same importance as C_{i_q}, than it is $I_p = I_q$. Expression (2) gives the maximum value of the scale for comparing the criteria r.

$$r = \max\{|S_1|, |S_2|, \ldots, |S_k|\} \quad (2)$$

Step 4. Based on the defined maximum value of the scale for comparing the criteria, coefficient of elasticity is determined $r_0 \in N$ which should satisfy the condition that $r_0 > r$.

Step 5. The calculation of the criterion influence function is realized in the following way:

$$f(C_{i_p}) = \frac{r_0}{i \cdot r_0 + I_{i_p}} \quad (3)$$

where *i* is the number of levels / subsets into which the criterion is classified, r_0 represents the coefficient of elasticity, while $I_{i_p} \in \{0, 1, \ldots, r\}$ represents the value assigned to the criterion C_{i_p} within the observed level.

Step 6. Calculation of optimal values of weight coefficients of criteria:

$$w_1 = \frac{1}{1 + f(C_2) + \cdots + f(C_n)} \quad (4)$$

The values of the weighting coefficients of the other criteria:

$$w_j = f(C_j) \cdot w_1 \quad (5)$$

where in $j = 2, 3, \ldots, n$, and n the total number of criteria.

If expert decision-making is performed, as previously stated, after each expert determines the values of weighting coefficients, the aggregation of individual judgments according to the considered criterion (A_{ij}) is started (Blagojević et al., 2017). In the A_{ij} method, to obtain the group coefficient, the weighted geometric mean method is used, which is calculated as the *nth* root of the product of all elements of the data set using expression (6):

$$\bar{w}_{jC_1} = \sqrt[n]{w_{j1} * w_{j2} * \ldots * w_{jn}} = \sqrt[n]{\prod_{i=1}^{n} w_j} \quad (6)$$

where in $\bar{w}_{jC_1}$ combined weighting factor for the criterion C_1, w_{j1} expert weighting factor (E_1) and n number of weighting coefficients according to the given criterion.

3.2 Fuzzy sets

In classical set theory, the membership of elements in a set is estimated in a binary sense according to the bivalent condition - the element either belongs or does not belong to the set (Chatterjee & Stević, 2019). However, it is not always possible to make a clear division, especially of complex phenomena, which cannot be easily described by traditional mathematical methods, especially when the goal is to find an approximately good solution (Bojadziev & Bojadziev, 1996).

Modeling using fuzzy sets has been shown to be an effective way of formulating decision-making problems, where available input information is subjective or imprecise (Zimmermann, 1998). Fuzzy sets are sets whose elements have membership degrees. The theory of obscure sets was first introduced by Zadeh (1965), whose application enables decision-makers to deal effectively with uncertainties. Since then, fuzzy sets have been used by many researchers in solving various problems alone or in combination with other methods of multi-criteria decision-making. Thus, Kushwaha et al. (2020) and Panchal et al. (2019a, 2019b) use Fuzzy FMEA to assess risk and improve safety in various engineering systems. Also Pamučar et al. (2016) use Fuzzy Logic System of Type 2 to assess the risk of natural and other disasters in the Republic of Serbia while Božanć et al. (2015) in risk assessment when overcoming water obstacles in a defense operation. Similar to the previous one, Gopal & Panchal (2021) use the Fuzzy Lambda-Tau (λ-τ) approach in the dairy processing industry. The Lambda-Tau fuzzy method was also applied when determining the time interval of regular maintenance of a coal-fired thermal power plan (Panchal et al., 2020) as well as when analyzing the performance problems of a chemical process plan (Panchal & Srivastava, 2019).

Fuzzy sets are used mainly with triangular (TFN), trapezoidal and Gaussian fuzzy numbers. A fuzzy set Ã is a set of ordered pairs consisting of elements x of the universal set H and a certain degree of affiliation $\mu_{\tilde{A}}(h)$, shape $\tilde{A}=\{ (x, \mu_{\tilde{A}}(x)) \mid x \in X, \mu_{\tilde{A}}(x) \in [0,1]\}$(Zadeh, 1965). The membership function of the $\mu_{\tilde{A}}$ fuzzy set Ã is the mapping $\mu_{\tilde{A}}: X \rightarrow [0,1]$, where Ã is a subset of the universal set H.

Due to its fairly simple membership function, the triangular fuzzy number is one of the most commonly used fuzzy numbers, is defined by the following form:

$$\mu_{\tilde{A}} = \begin{cases} 1-\dfrac{m-x}{l}, & m-l \le x \le m \\ 1-\dfrac{x-m}{u}, & m \le x \le m+u \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

Fuzzy number is denoted as $\tilde{A}=(l,m,u)$. The value of m mark the basic value of the fuzzy number, a l deviation from the left, that is, u to the right of the modal value.

A very important concept associated with the application of fuzzy numbers is the dephasing process, which converts a fuzzy number into a real number. Several methods for performing dephasification can be found in the literature. The most widely used dephasification procedure is the centroid method, which is also known as the center of gravity or the Kwong method (Kwong & Bai, 2003). The triangular fuzzy of the number Ã = (l, m, u) is translated into a real number using the following expression:

$$M = \frac{(l+4*m+u)}{6} \tag{8}$$

3.3. Fuzzy MABAC method

Multi-Attributive Border Approximation area Comparasion (MABAC)

The MABAC method is a reliable tool for rational decision-making (Pamučar & Ćirović, 2015). So far, it has been used in a large number of works independently or in one of the modifications. Alinezhad & Khalili (2019) in their book, among others, deal with the MABAC method. Sun et al. (2017) use the MABAC method to determine the priority of patient care. Using a modified rough method, AHP-MABAC, Sharma et al. (2018) determined the priority stations in the Indian Railways. Some authors combine the basic MABAC motor with fuzzy sets q-ROFS (Wang, 2020). Wei et al. (2019) apply the MABAC meter in ranking medical equipment suppliers. Božanić et al. (2016) applied the MABAC method in support of decision-making on the use of force in a defensive operation. Liang et al. (2019) use the MABAC method when assessing risk. Also, using this method, some authors selected the most suitable route of new lines in road and railway traffic (Luo et al., 2019). When defining the new interval-valued fuzzy-rough numbers (IVFRN) method, Pamučar et al. (2018) modified the BWM (Best – Worst method) and MABAC methods. Mishra et al. (2020) select a programming language using the MABAC method. Due to its consistency mentioned earlier, the MABAC method can be found in many more papers.

The fuzzy MABAC method solves the problem in three steps (Bobar et al., 2020):

Step 1. Forming the initial decision matrix ($\tilde{X}$).

The first thing is to do assessment *m* alternatives according to *n* criteria. Alternatives are shown in vector form $A_i = \left(\tilde{x}_{i1}, \tilde{x}_{i2} ..., \tilde{x}_{in}\right)$.

$$\tilde{X} = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ \begin{matrix} A_1 \\ A_2 \\ \dots \\ A_m \end{matrix} & \multicolumn{4}{c}{\begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{11} & \tilde{x}_{22} & & \tilde{x}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix}} \end{matrix} \tag{9}$$

Step 2. Normalization the initial matrix ($\tilde{X}$)

$$\tilde{X} = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ \begin{matrix} A_1 \\ A_2 \\ \dots \\ A_m \end{matrix} & \multicolumn{4}{c}{\begin{bmatrix} \tilde{n}_{11} & \tilde{n}_{12} & \dots & \tilde{n}_{1n} \\ \tilde{n}_{11} & \tilde{n}_{22} & & \tilde{n}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{n}_{m1} & \tilde{n}_{m2} & \dots & \tilde{n}_{mn} \end{bmatrix}} \end{matrix} \tag{10}$$

Elements of a normalized matrix ($\tilde{N}$) are determined by the equation:

a) For benefit (max) type criteria

$$\tilde{n}_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{11}$$

b) For Cost (min) type criteria

$$\tilde{n}_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{12}$$

Step 3. Calculate the elements from the weighted matrix ($\tilde{V}$).

$$\tilde{v}_{ij} = w_i * \tilde{n}_{ij} + w_i \tag{13}$$

n_{ij} is the elements of a normalized matrix ($\tilde{N}$), and w_i is the weighting coefficients of the criteria. Using equation (19) we receive a weighted matrix

$$\tilde{V} = \begin{bmatrix} \tilde{v}_{11} & \tilde{v}_{12} & \dots & \tilde{v}_{1n} \\ \tilde{v}_{21} & \tilde{v}_{22} & \dots & \tilde{v}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{v}_{m1} & \tilde{v}_{m2} & \dots & \tilde{v}_{mn} \end{bmatrix} \tag{14}$$

Step 4. Determining the matrix of the approximate boundary area ($\tilde{G}$).

Boundary approximation area (BAA) is determined based on the expression:

$$\tilde{g}_i = \left(\prod_{j=1}^{m} \tilde{v}_{ij} \right)^{1/m} \tag{15}$$

After calculating the value $\tilde{g}_i$ for each criterion, a matrix of boundary approximate domains is formed $\tilde{G}$.

$$\begin{array}{cccc} & C_1 & C_2 & \dots & C_n \\ \tilde{G} = & [\tilde{g}_1 & \tilde{g}_2 & \dots & \tilde{g}_n] \end{array} \tag{16}$$

Step 5. The calculation of the distance of the alternatives from the boundary approximate domain is obtained as follows:

$$\tilde{Q} = \begin{bmatrix} \tilde{q}_{11} & \tilde{q}_{12} & \dots & \tilde{q}_{1n} \\ \tilde{q}_{21} & \tilde{q}_{22} & & \tilde{q}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{q}_{m1} & \tilde{q}_{m2} & \dots & \tilde{q}_{mn} \end{bmatrix} \tag{17}$$

$$\tilde{Q} = \tilde{V} - \tilde{G} \tag{18}$$

Alternative A_i may belong to the boundary approximate domain ($\tilde{G}$), upper approximate area ($\tilde{G}^+$) or the lower approximate domain ($\tilde{G}^-$).

Belonging to an alternative A_i area of approximation ($\tilde{G}$, $\tilde{G}^+$ or $\tilde{G}^-$) is determined on the basis of the equation (19).

$$A_i \in \begin{cases} \tilde{G}^+ & if \quad \tilde{q}_{ij} \succ 0 \\ \tilde{G} & if \quad \tilde{q}_{ij} = 0 \\ \tilde{G}^- & if \quad \tilde{q}_{ij} \prec 0 \end{cases} \tag{19}$$

Step 6. Ranking alternatives.

Through the sum of the distances of the alternatives from the boundary approach area ($\tilde{q}_i$) the calculation of the values of the criterion functions for alternatives was received. The final value of the criterion functions of the alternatives was received by calculating the sum of the elements of the matrix Q by rows.

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{q}_{ij},\ j = 1,2,\dots,n,\ i = 1,2,\dots,m \tag{20}$$

4. Application of the hybrid model of multi-criteria decision making

The LBWA – Fuzzy MABAC hybrid model consists of four phases. In the first phase of the model, based on expert assessment, the criteria are defined. In the second phase, the calculation of the weight coefficients of the criteria is realized using expert assessment and the LBWA method. In the third phase, the best alternative is selected using the fuzzy MABAC method. The last phase includes the sensitivity analysis of the developed model and the correlation of ranks.

4.1. Criteria for choosing the firing position

In the first phase, the criteria are defined that in the further work directly affect the choice of the best alternative, ie. optimal locations for the firing position. Defining criteria and their weighting coefficients represents an important phase for decision-making models (Pamučar et al., 2016). Due to the complexity of the problem in defining the selection criteria, experts were hired. Experts identified eight criteria for the considered problem, which are listed from C_1 to C_8.

The criteria for selecting the location of the fire position (FP) of the battalion fire group (BFG), which is formed by a company of 120 mm mortars, were defined on the basis of expert opinion, and the data from the rules served as the basis for the survey.

The selection of the most favorable location of BFG is made on the basis of eight criteria:

C_1 - distance to the target, expressed in meters (ideal location is generally defined at 1/3 of the range of the weapon from the front end of its own forces when the unit is in attack, or 2/3 when in defense).

C_2 - the ability to observe the firing position by the enemy. In the professional literature, the stated criterion is defined as the shelter of the firing position, and on that basis, the division into sheltered, semi-sheltered and discovered (un sheltered) firing position was made. The detected firing position allows direct aiming at the target. On it the enemy can spot people and tools. The semi-sheltered firing position makes it impossible for the enemy to visually spot people, but it can detect it by smoke and flash when firing a mine. The sheltered firing position prevents the enemy from observing from the ground or detecting the firing position by the smoke and flash of a fired mine.

C_3 - masking conditions (terrain characteristics that enable successful masking of BFG and movement of parts or the whole BFG).

C_4 - soil bearing capacity - terrain characteristics on which the accuracy of shooting depends. When shooting from too hard ground, the ground bounces off the ground, while on soft ground it collapses, which requires additional soil reinforcement.

C_5 - the size of the parallax expressed in thousands of parts of the angle. The parallax of the target is the angle between the line of sight and the line of fire. If it is in the range from 0-00 to 3-00 it is small, from 3-00 to 5-00 it is medium and over 5-00 it is large.

C_6 - distance of the observation post from the firing position. The distance of the observation post from the firing position directly affects the duration and accuracy of the correction. The smaller the distance, the more precise the correction will be, and thus the faster it will be completed. Based on that, there is a division into near and far observatories. The observation post is close if it is within 10% of the shooting distance.

C_7 - access conditions. The approach conditions directly affect the speed of the firing position, and thus the time of preparation of the unit for opening fire. Having in mind the mass of individual parts of the 120 mm mortar, it is not at all negligible whether the tools can be brought by motor vehicle to the firing position or the handlers have to carry them by hand.

C_8 - distance to own units. The duration of the correction also depends on the distance of the firing position to one's own units. The closer the units are to the firing position, the easier it is to make a correction, and thus in a shorter time.

The set of criteria Cj consists of two subsets, a subset of the benefit type criteria, which means that a higher value of the criterion is more desirable, ie. better, denoted by C + and a subset of cost-type criteria, which means that a smaller value is more desirable, ie. better marked with C -. In this particular case, the subset of criteria C^+ includes criteria C_2, C_3, C_4 and C_7, while the subset of criteria C^- includes criteria C_1, C_5, C_6 and C_8.

The values of criteria C_1 and C_8 are shown as numerical values while the values of criteria C_2 are shown through a linguistic scale from 1 to 5 as seen in Table 1.

Table 1. Linguistic descriptors for criterion C_2

Linguistic descriptor	discovered (Ds)	semi-sheltered (SS)	sheltered (S)
Assigned numeric value	1	3	5

The values of criteria C_3, C_4, C_5, C_6 and C_7 are presented as fuzzy linguistic descriptors (table 2, table 3 and table 4).

Table 2.Fuzzy linguistic descriptors for criteria C_3, C_4, C_7

Linguistic condition	fuzzy number
Bad (B)	(0, 1, 3)
Good (G)	(2, 3, 5)
Excellent (E)	(4, 5, 5)

Table 3. Fuzzy linguistic descriptor for criterion C_5

Linguistic condition	Fuzzy number
Small (S)	(0, 2, 3.5)
Medium (M)	(2.5, 4, 5.5)
Large (L)	(4.5, 6, 7.5)

Table 4: Fuzzy linguistic descriptor for criterion C_6

Linguistic condition	fuzzy number
Close (C)	(0, 450, 600)
Remote (R)	(480, 640, 1000)

4.2. Calculation of weight coefficients of criteria using LBWA method

In the second phase, the calculation of the weight coefficients of the criteria is performed using the LBWA method, in the previously described manner. After the selection of the most important criteria by the experts, the determination of the weighting criteria is presented in this text. Determination of weighting coefficients is shown for one expert (E_1). As 11 experts participated in the research, in the end the aggregation of weight coefficients from all of them was performed and the weight coefficients were obtained, which were further used when choosing the firing position of the 120 mm mortar using the MABAC method.

Step 1: For the most important, the E_1 expert chose criterion C_2.

Step 2: The criteria are classified into three levels:

$S_1 = \{C_2, C_8\}$,

$S_2 = \{C_1, C_6, C_4\}$,

$S_3 = \{C_7, C_5, C_3\}$.

Step 3: Based on expression (2), the maximum value of the scale for comparing the criteria is defined

$r = \max\{|S_1|, |S_2|, |S_3| = 3$

Based on the comparison of criteria according to their significance, C_2 gets the value $I_2 = 0$ as the most significant criterion, while other criteria according to their importance in their sub-levels, get the following values:

S_1: $I_8=1$;

S_2: $I_1=1$, $I_6=2$, $I_4=4$;

S_3: $I_7=1$, $I_5=3$, $I_3=3$.

Step 4: Based on the defined maximum value of the scale for comparing the criteria $r = 3$, the coefficient of elasticity $r_0 = 4$ is defined.

Step 5: Using expression (3), the influence functions of the criteria were calculated:

$$f(C_2) = \frac{4}{1*4+0} = 1, \quad f(C_8) = \frac{4}{1*4+1} = 0.8,$$
$$f(C_1) = \frac{4}{2*4+1} = 0.444, \quad f(C_6) = \frac{4}{2*4+2} = 0.4, \quad f(C_4) = \frac{4}{2*4+4} = 0.333,$$
$$f(C_7) = \frac{4}{3*4+1} = 0.308, \quad f(C_5) = \frac{4}{3*4+3} = 0.267, \quad f(C_3) = \frac{4}{3*4+3} = 0.267$$

Step 6: Using expression (4), the weight coefficient of the most influential criterion was obtained

$$w_2 = \frac{1}{1+0.8+0.444+0.4+0.333+0.308+0.267+0.267} = 0.262$$

while the values of weight coefficients of the remaining criteria were obtained by applying the expression (5):

$w_1 = 0.262*0.444 = 0.116,$

$w_3 = 0.262*0.267 = 0.209,$

…

$w_8 = 0.262*0.8 = 0.209.$

Based on the previous, the vector of expert weight coefficients (E_1) was obtained:

w_{j1}=(0.116, 0.262, 0.070, 0.087, 0.070, 0.105, 0.081, 0.209).

Using the expression (6), the aggregation of weight coefficients obtained from the experts was performed, on the basis of which a vector of weight coefficients was formed:

w_j =(0.187, 0.234, 0.072, 0.104, 0.094, 0.085, 0.067, 0.156).

After determining the weight coefficients of the criteria, it is possible to move on to the next phase of the model.

4.3. Choosing the best alternative using the fuzzy MABAC method

The third phase of the model involves selecting the best alternative for the firing position using the fuzzy MABAC method as described previously.

The paper discusses six potential locations-alternatives to the firing position of the mortar unit. The characteristics of the considered locations were obtained by the intelligence-reconnaissance work of the superior command.

Step 1. The first step is to form the initial matrix according to expression (9), which is shown in Tables 5 and 6.

Table 5 shows the initial decision matrix. Numerical and linguistic values are given for the considered alternatives according to the stated criteria.

Table 5. Initial decision matrix

Alt.	Criteria							
	C_1 (min)	C_2 (max)	C_3 (max)	C_4 (max)	C_5 (min)	C_6 (min)	C_7 (max)	C_8 (min)
A_1	5850	S	E	G	S	C	G	1000
A_2	4925	SS	G	E	M	R	E	950
A_3	3762	Ds	G	E	L	R	E	1250
A_4	4558	SS	B	G	M	C	G	1187
A_5	5321	S	E	B	S	C	B	1530
A_6	4789	S	G	G	L	R	G	1987
w_i	0.187	0.234	0.072	0.104	0.094	0.085	0.067	0.156

Linguistic values, in Table 6, are quantified into numerical ones. Criterion C_2 is shown as a real number after quantification while criteria C_3 to C_7 are shown as triangular fuzzy numbers.

Table 6. Quantification of the initial decision matrix

Alt	Criteria							
	C_1 (min)	C_2 (max)	C_3 (max)	C_4 (max)	C_5 (min)	C_6 (min)	C_7 (max)	C_8 (min)
A_1	5850	5	(4, 5, 5)	(2, 3, 5)	(0, 2, 3.5)	(0, 450, 600)	(2, 3, 5)	1000
A_2	4925	3	(2, 3, 5)	(4, 5, 5)	(2.5, 4, 5.5)	(480, 640, 1000)	(4, 5, 5)	950
A_3	3762	1	(2, 3, 5)	(4, 5, 5)	(4.5, 6, 7.5)	(480, 640, 1000)	(4, 5, 5)	1250
A_4	4558	3	(0, 1, 3)	(2, 3, 5)	(2.5, 4, 5.5)	(0, 450, 600)	(2, 3, 5)	1187
A_5	5321	5	(4, 5, 5)	(0, 1, 3)	(0, 2, 3.5)	(0, 450, 600)	(0, 1, 3)	1530
A_6	4789	5	(2, 3, 5)	(2, 3, 5)	(4.5, 6, 7.5)	(480, 640, 1000)	(2, 3, 5)	1987

Step 2. Normalization of initial matrix elements (*X*).

Normalization of elements from the confirmed initial decision matrix was performed using expressions (11) and (12), and the results are shown in Table 7.

Table 7. Normalized matrix (N)

Alt.	Criteria					
	C_1 (min)	C_2 (max)	C_3 (max)	...	C_7 (max)	C_8 (min)
A_1	0	1	(0.8, 1, 1)	...	(0.4, 0.6, 1)	0.952
A_2	0.443	0.500	(0.4, 0.6, 1)	...	(0.8, 1, 1)	1
A_3	1.000	0.000	(0.4, 0.6, 1)	...	(0.8, 1, 1)	0.771
A_4	0.619	0.500	(0, 0.2, 0.6)	...	(0.4, 0.6, 1)	0.771
A_5	0.253	1.000	(0.8, 1, 1)	...	(0, 0.2, 0.6)	0.441
A_6	0.508	1.000	(0.4, 0.6, 1)	...	(0.4, 0.6, 1)	0

Step 3. Calculation of elements from a weighted matrix (*V*).

The elements from the weighted matrix (*V*) are calculated on the basis of expression (13) which is shown in Table 8.

Table 8. Difficult normalized matrix (V)

Alt.	Criteria					
	C_1 (min)	C_2 (max)	C_3 (max)	...	C_7 (max)	C_8 (min)
A_1	0.187	0.468	(0.130, 0.144, 0.144)	...	(0.094, 0.107, 0.134)	0.305
A_2	0.270	0.351	(0.101, 0.115, 0.144)	...	(0.120, 0.134, 0.134)	0.312
A_3	0.374	0.234	(0.101, 0.115, 0.144)	...	(0.120, 0.134, 0.134)	0.267
A_4	0.303	0.351	(0.072, 0.087, 0.115)	...	(0.094, 0.107, 0.134)	0.277
A_5	0.234	0.469	(0.130, 0.144, 0.144)	...	(0.067, 0.080, 0.107)	0.225
A_6	0.282	0.469	(0.101, 0.115, 0.144)	...	(0.094, 0.107, 0.134)	0.156

Step 4. Determination of the boundary approximate domain matrix (G)

The boundary approximate area was obtained by applying expression (15), which is shown in Table 9.

Table 9. Boundary approximate domain matrix

BAA	Criteria					
	C_1 (min)	C_2 (max)	C_3 (max)	...	C_7 (max)	C_8 (min)
g_i	0.269	0.379	(0.104, 0.118, 0.139)	...	(0.096, 0.110, 0.129)	0.251

Step 5. Calculating the distance of the alternative from the area of the approximate boundary for the matrix elements (Q)

The distance of alternatives from BAA was obtained by applying expressions (18) and (19), Table 10.

Table 10. Matrix distance alternatives from BAA

Alt.	Criteria					
	C_1 (min)	C_2 (max)	C_3 (max)	...	C_7 (max)	C_8 (min)
A_1	-0.082	0.089	(-0.009, 0.026, 0.040)	...	(-0.035,-0.003, 0.038)	0.054
A_2	0.001	-0.028	(-0.038,-0.003, 0.040)	...	(-0.009, 0.024, 0.038)	0.062
A_3	0.105	-0.145	(-0.038,-0.003, 0.040)	...	(-0.009, 0.024, 0.038)	0.017
A_4	0.034	-0.028	(-0.067,-0.032, 0.012)	...	(-0.035,-0.003, 0.038)	0.026
A_5	-0.035	0.089	(-0.009, 0.026, 0.040)	...	(-0.062,-0.030, 0.011)	-0.026
A_6	0.013	0.089	(-0.038,-0.003, 0.040)	...	(-0.035,-0.003, 0.038)	-0.094

Step 6. Ranking alternatives.

To make it easier to represent the final rank of the alternatives using expression (8) the triangular fuzzy number is translated into a real number. According to expression (20), by calculating the sum of the elements of the matrix Q by rows, the final values of the criterion functions of the alternatives were obtained, which is shown in Table 11.

Table 11. Rank of alternatives by MABAC method

Alt.	Criteria								Q_j	Rank
	C_1 (min)	C_2 (max)	C_3 (max)	C_4 (max)	C_5 (min)	C_6 (min)	C_7 (max)	C_8 (min)		
A_1	-0.082	0.089	0.022	-0.002	0.027	0.012	-0.002	0.054	0.120	1
A_2	0.001	-0.028	-0.002	0.032	0.001	-0.011	0.021	0.062	0.077	2
A_3	0.105	-0.145	-0.002	0.032	-0.024	-0.011	0.021	0.017	-0.006	5
A_4	0.034	-0.028	-0.030	-0.002	0.001	0.012	-0.002	0.026	0.011	4
A_5	-0.035	0.089	0.022	-0.044	0.027	0.012	-0.028	-0.026	0.019	3
A_6	0.013	0.089	-0.002	-0.002	-0.024	-0.011	-0.002	-0.094	-0.032	6

Based on the obtained results, it is concluded that alternative A_1 is ranked first, ie that the ranking of alternatives is as follows: $A_1 > A_2 > A_5 > A_4 > A_3 > A_6$.

4.4. Sensitivity analysis

The fourth phase includes testing the sensitivity of the applied model, in order for the decision-maker to receive confirmation of the quality of the obtained solution, ie to determine how changes in the weight of criteria lead to changes in alternative ranks (Tešić & Božanić, 2018; Durmić et al., 2020). Checking the stability of the used methods of multi-criteria decision-making is an indispensable step in the process of developing a model to support decision-making (Pamučar et al., 2017). Stability was examined by changing the weight coefficients wi, ie by changing the value of the coefficient of elasticity r_0, whose value in the work is r_0 = 4. Table 12 shows the influence of the value of r_0 on the change in the rank of the alternative:

Table 12: Rank alternative depending on r_0

Alt.	$r_0 = 4$	$r_0 = 5$	$r_0 = 6\text{-}9$	$r_0 = 10\text{-}20$
A_1	1	1	1	1
A_2	2	2	2	2
A_3	5	5	5	4
A_4	4	4	3	3
A_5	3	3	4	5
A_6	6	6	6	6

Based on Table 12, it can be noticed that with the change of the weight coefficient, ie the coefficient of elasticity, the model shows stability. Three alternatives (A_1, A_2 and A_6) retain the rank regardless of the value of r_0 while the other alternatives suffer changes of rank for r_0 = 5, r_0 = 6 and r_0 = 10. For the values r_0 = 7, r_0 = 8 and r_0 = 9, the rank is identical as for r_0 = 6. Also, for r_0 = 11-20 the rank is identical as for r_0 = 10.

In order to establish the correlation of the ranks obtained by changing r_0, the Spearman coefficient was used as in expression (20):

$$S = 1 - \frac{6\sum_{i=1}^{n} D_i^2}{n(n^2-1)} \tag{21}$$

where D_i represents the difference of rank according to the given r_0 and rank in the corresponding r_0, and n the number of ranked alternatives. The Spiraman coefficient belongs to the value interval [-1,1] (Radovanović et al., 2020). When the ranks of the alternatives completely match the Spearman coefficient is 1 ("ideal positive correlation"), when the ranks are completely opposite the Spearman coefficient is -1 ("ideal negative correlation"), ie when S = 0 the ranks are uncorrelated. The values of the Spearman coefficient for the considered problem are shown in Table 13.

Table 13: Spearman coefficient values

	$r_0 = 4$	$r_0 = 5$	$r_0 = 6\text{-}9$	$r_0 = 10\text{-}20$
$r_0 = 4$	1	1	0.94	0.83
$r_0 = 5$		1	0.94	0.83
$r_0 = 6\text{-}9$			1	0.94
$r_0 = 10\text{-}20$				1

From the results shown in Table 13, it can be concluded that the values of the Spearman coefficient for all values of r_0 are extremely high, ie that there is an ideal positive correlation of ranks. There is no deviation from the ideal positive correlation as well as the negative correlation. Based on the above, it is possible to conclude that the model has sufficient sensitivity.

5. Conclusion

On a hybrid model based on the LBWA and fuzzy MABAC method, the paper explains the process of creating a multi-criteria decision model. Through a multi-criteria model, the paper solves the problem of choosing the location of the firing position for mortar units of company size MB 120 mm, which has not been considered in this way in the existing literature so far.

The paper describes in detail the steps of the LBWA and fuzzy MABAC methods. The experts determined eight criteria for influencing the choice of firing position. Further, the experts identified the most significant criterion, defined the levels of significance and determined the values of the criteria by levels. Part of the criteria, of the linguistic type, obtained numerical values using fuzzy linguistic and linguistic descriptors.

As the best choice-alternative, the MABAC method suggests the A_1 alternative. Alternative A_1 in relation to the others, has the largest battle of criteria belonging to the above approximate domain.

As the last phase, the sensitivity analysis of the presented model was performed in the paper, by changes in the weight coefficients of the criteria (by changing the coefficient of elasticity) from r_0 = 4 to r_0 = 20. The results of the analysis indicate sufficient stability of the model. The first-ranked alternative A_1 retains the first position regardless of the growth of the coefficient of elasticity r_0. Also, the Spearman coefficient has a great value, which shows that there is an ideal positive correlation of ranks.

Based on the existing literature, the LBWA method has not been combined with the MABAC method so far. Based on the results, presented in the model, it is concluded that the combination of these two methods gives consistent results. Further research should focus on testing the applied model through new problems, as well as the application of other methods to the existing problem.

The presented model of mortar firing position can have great application in military management. The application of the methods used significantly shortens the time in the decision-making process, which is very important in an uncertain environment.

References

Abdel-Basset, M., Gamal, A., Chakrabortty, R. K., & Ryan, M. (2021). A new hybrid multi-criteria decision-making approach for location selection of sustainable offshore wind energy stations: A case study. Journal of Cleaner Production, 280(2), 124462.

Alinezhad, A., & Khalili, J. (2019). New Methods and Applications in Multiple Attribute Decision Making (MADM). International Series in Operations Research & Management Science. Cham: Springer.

Blagojević, B., Srđević, B., Srđević, Z., & Zoranović, T. (2017). Group decision making using the analytic hierarchy process. Annals of Agronomy, 41(1), 30-39.

Bobar, Z., Božanić, D., Djurić, K., & Pamučar, D. (2020). Ranking and Assessment of the Efficiency of Social Media using the Fuzzy ANP-Z Number Model - Fuzzy MABAC. Acta Polytechnica Hungarica, 17(3), 43-70.

Bojadziev, G., & Bojadziev, M. (1996). Advances in Fuzzy Systems — Applications and Theory: Fuzzy sets, fuzzy logic, applications. World Scientific.

Božanić D., Slavković R., & Karović S. (2015). Model of Fuzzy Logic Application to the Assessment of Risk in Overcoming the Obstacles during an Army Defensive Operation, Vojno delo, 67(4), 240-260.

Božanić, D., & Pamučar, D. (2010). Evaluating locations for river crossing using fuzzy logic. Vojnotehnički glasnik/Military Technical Courier, 58(1), 129-145.

Božanić, D., Pamučar, D., & Karović, S. (2016). Application the mabac METHOD in support of decision-making on the use of force in a defensive operation, Tehnika, 66(1), 129-136.

Božanić, D., Ranđelović, A., Radovanović, M., & Tešić, D. (2020). A hybrid LBWA - IR-MAIRCA multicriteria decision-making model for determination of constructive elements of weapons, Facta Universitatis Series: Mechanical Engineering, 18(3), 399-418.

Chatterjee, P., & Stević, Ž. (2019). A two-phase fuzzy AHP - fuzzy TOPSIS model for supplier evaluation in manufacturing environment. Operational Research in Engineering Sciences: Theory and Applications, 2(1), 72-90.

Contreras I., & O'Kelly M. (2019). Hub Location Problems. In: Laporte G., Nickel S., Saldanha da Gama F. (Eds.), Location Science. Cham: Springer.

Darbari, J. D., Agarwal, V., & Jha, P. C. (2016). Multi Criteria Decision Making Model for Optimal Selection of Recovery Facility Location and Collection Routes for a Sustainable Reverse Logistics Network Under Fuzzy Environment. Recent Advances in Mathematics, Statistics and Computer Science, 29-39, doi.org/10.1142/9789814704830_0003.

Department of the Army. (2017). Mortars, Training Circular Washington No. 3-22.90.

Durmić, E., Stević, Ž., Chatterjee, P., Vasiljević, M., & Tomašević, M.. (2020). Sustainable supplier selection using combined FUCOM–Rough SAW model. Reports in mechanical engineering, 1(1), 34-43.

Gopal, N., & Panchal, D. (2021). A structured framework for reliability and risk evaluation in the milk process industry under fuzzy environment. Facta Universitatis Series: Mechanical Engineering https://doi.org/10.22190/FUME201123004G, (Online first).

Hamurcu, M., & Eren, T. (2019). An Application of Multicriteria Decision-making for the Evaluation of Alternative Monorail Routes, Mathematics, 7(1), 16.

Jenzen-Jones, N.R. (2015). Guided Mortar System. Research Note No. 3. Geneva: Small Arms Survey.

Karatas, M., Yakici, E., & Razi, N. (2019). Military Facility Location Problems: A Brief Survey. In Tozan, H., & Karatas, M. (Eds.), Operations Research for Military Organizations (pp.1-27). Hershey, PA: IGI Global.

Küçükaydın, H., & Aras, N. (2020). Gradual covering location problem with multi-type facilities considering customer preferences. Computers & Industrial Engineering, 147, 106577.

Kurtov, D., Božanić, D., & Pamučar, D. (2014). The choice of areas for firing position of Brigade Artillery Group in a defensive operation using the VIKOR method. In Proceedings of 17th DQM Internacional Conference (pp.705-710), Belgrade.

Kushwaha, D. K., Panchal, D., & Sachdeva, A. (2020). Risk analysis of cutting system under intuitionistic fuzzy environment, Reports in Mechanical Engineering, 1(1), 162-173.

Kwong, C. K., & Bai, H. (2003). Determining the importance weights for the customer requirements in QFD using a fuzzy AHP with an extent analysis approach. IIE Transactions, 35(7), 619-626.

Liang, W., Zhao, G., Wu, H., & Dai, B. (2019). Risk assessment of rockburst via an extended MABAC method under fuzzy environment. Tunnelling and Underground Space Technology, 83, 533-544.

Liang, Y., Liu, F., Lim, A., & Zhang, D. (2020). An integrated route, temperature and humidity planning problem for the distribution of perishable products. Computers & Industrial Engineering, 147, 106623.

Luo, S-Z., Liang, W-Z. (2019). Optimization of roadway support schemes with likelihood-based MABAC method. Applied Soft Computing. 80, 80-92.

Military Encyclopedia (Only in Serbian: Vojna enciklopedija). (1973). Belgrade: Military Paper Office.

Mishra, A.R., Chandel, A., & Motwani, D. (2020). Extended MABAC method based on divergence measures for multicriteria assessment of programming language with interval-valued intuitionistic fuzzy sets. Granular Computing, 5, 97–117.

Ortiz-Astorquiza, C., Contreras, I., & Laporte, G. (2018). Multi-level facility location problems. European Journal of Operational Research, 267(3), 791-805.

Pamučar, D, Božanić, D., & Kurtov, D. (2016). Fuzzification of the Saaty's scale and a presentation of the hybrid fuzzy AHP-TOPSIS model: an example of the selection of a brigade artillery group firing position in a defensive operation. Vojnotehnički glasnik/Military technical courier, 64(4), 966-986.

Pamučar, D., & Ćirović, G. (2015). The selection of transport and handling resources in logistics centres using Multi Attributive Border Approximation area Comparison (MABAC). Expert Systems with Applications, 42(6), 3016-3028.

Pamučar, D., Božanić, D., & Komazec, N. (2016). Risk Assessment of Natural Disasterts using Fuzzy Logic System Type-2, Management - Journal for Theory and Practice Management, 21(80), 23-32.

Pamučar, D., Božanić, D., & Milić, A. (2016). Selection of a course of action by Obstacle Employment Group based on a fuzzy logic system. Yugoslav Journal of Operations Research, 26(1), 75-90.

Pamučar, D., Božanić, D., & Ranđelović, A.. (2017). Multi-criteria decision making: An example of sensitivity analysis. Serbian Journal of Management, 12(1), 1-27.

Pamučar, D., Ćirović, G., & Božanić, D. (2019). Application of interval valued fuzzy-rough numbers in multi-criteria decision making: The IVFRN-MAIRCA model. Yugoslav Journal of Operations Research, 29(2), 221-247.

Pamučar, D., Deveci, M., Canıtez. F., & Lukovac, V. (2020a). Selecting an airport ground access mode using novel fuzzy LBWA-WASPAS-H decision making model. Engineering Applications of Artificial Intelligence, 93, 103703.

Pamučar, D., Petrović, I., & Ćirović, G. (2018). Modification of the Best–Worst and MABAC methods: A novel approach based on interval-valued fuzzy-rough numbers. Expert Systems with Applications, 91, 89-106.

Pamučar, D., Žižović, M., Marinković, D., Doljanica, D., Jovanović, V., S., & Brzaković, P. (2020b). Development of a Multi-Critria Model for Sustainable Reorganization of a Nealthcare System in an Emergency Situation Caused by the COVID-19 Pandemic. Sustainability, 12(18), 7504.

Pan, Y., Zhang, L., Koh, J., & Deng, Y. (2021). An adaptive decision making method with copula Bayesian network for location selection. Information Sciences, 544, 56-77.

Panchal D., Tyagi M., Sachdeva A., & Garg R.K. (2020) Reliability Analysis of Complex Repairable System in Thermal Power Plant. In: Ram M., & Pham H. (Eds.) Advances in Reliability Analysis and its Applications, Springer Series in Reliability Engineering (pp. 361-372). Cham: Springer.

Panchal, D., & Srivastava, P. (2019). Qualitative analysis of CNG dispensing system using fuzzy FMEA–GRA integrated approach. International Journal of System Assurance Engineering and Management, 10, 44–56.

Panchal, D., Chatterjee, P., Yazdani, M., & Chakraborty, S. (2019a). A Hybrid MCDM Approach-Based Framework for Operational Sustainability of Process Industry. Advanced Multi-Criteria Decision Making for Addressing Complex Sustainability Issues (pp. 1-13). Hershey, PA: IGI Global (Chapter 1).

Panchal, D., Singh, A. K., Chatterjee, P., Zavadskas, E. K. &, Keshavarz-G. M. (2019b). A new fuzzy methodology-based structured framework for RAM and risk analysis. Applied Soft Computing, 74, 242-254.

Radovanović, M., Ranđelović, A., & Jokić, Ž. (2020). Application of hybrid model fuzzy ahp - vikor in selection of the most efficient procedure for rectification of the optical sight of the longrange rifle. Decision Making: Applications in Management and Engineering, 3(2), 131-148.

Sennaroglu, B., & Celebi, G. V. (2018). A military airport location selection by AHP integrated PROMETHEE and VIKOR methods. Transportation Research Part D: Transport and Environment, 59, 160-173.

Sharma, K., H., Roy, J., Kar, S., & Prentkovskis, O. (2018). Multi Criteria Evaluation Framework for Prioritizing Indian Railway Stations Using Modified Rough AHP-Mabac Method. Transport and Telecommunication Journal, 19(2), 113-127.

Stoilova, S. (2020). An Integrated Multi-Criteria Approach for Planning Railway Passenger Transport in the Case of Uncertainty. Symmetry, 12, 949.

Sun, R., Hu, J., Zhou., J., & Chen. X. (2017). A Hesitant Fuzzy Linguistic Projection-Based MABAC Method for Patients' Prioritization. International Journal of Fuzzy Systems, 20, 2144-2160.

Tešić, D., & Božanić, D. (2018). Application of the MAIRCA method in the selection of the location for crossing tanks under water, Tehnika, 68(6), 860-867.

Wang, J., Wei, G., Wei, C., & Wei, Y. (2020). MABAC method for multiple attribute group decision making under q-rung orthopair fuzzy environment. Defence Technology, 16(1), 208-216.

Wei, G., Wei, C., Wu, J., & Wang, H. (2019). Supplier Selection of Medical Consumption Products with a Probabilistic Linguistic MABAC Method, International Journal of Environmental Research and Public Health, 16(24), 5082.

Xu, X., Grace Guo, W., & Rodgers, M. D. (2020). A real-time decision support framework to mitigate degradation in perishable supply chains. Computers & Industrial Engineering, 150, 106905.

Zadeh, L.A. (1965). Fuzzy sets. Information and control, 8(3), 338-353.

Zimmermann, H.J. (1998). Fuzzy Set Theory and Its Applications. Boston: Kluwer.

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), 126-137.