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A HYBRID FUZZY AHP-MABAC MODEL: APPLICATION IN THE SERBIAN ARMY – THE SELECTION OF THE LOCATION FOR DEEP WADING AS A TECHNIQUE OF CROSSING THE RIVER BY TANKS

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Abstract: *In this paper is presented a hybrid model based on the fuzzified Analytical Hierarchical Process (AHP) method and the fuzzified Multi-Attributive Border Approximation Area Comparison (MABAC) method. The FAHP method is used for defining the weight coefficients of the criteria, while the FMABAC method is performed for the ranking of the alternatives. The fuzzification of the AHP method is carried out by defining a variable confidence interval for the values from the Saaty's scale, which is derived from the comparison in pairs and the degree of certainty of the decision-makers in the comparison they make. The application of the hybrid model is shown on the example of the ranking of the locations for deep wading as a technique of crossing the river by the Serbian Army tank units. Through the paper are elaborated the criteria which condition such choice; also, the application of the method in a particular situation is demonstrated.*

Key Words: *Fuzzy AHP (FAHP), Fuzzy MABAC (FMABAC), Location for River Crossing, Deep Wading, Tank.*

1. Introduction

A modern approach to decision-making increasingly implies the application of several methods with the tendency to exploit positive, i.e. to isolate/reject negative characteristics that different decision-making methods possess. This creates various hybrid models, which differ from case to case. The specificity of the case that is to be solved, and not rarely, the knowledge of the author, influence the choice of the methods which will form a hybrid model. The results of a large number of studies point to the fact that hybrid models provide significantly better results, compared to the application of classic problem solving methods.

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In this paper a hybrid model composed of two segments is created. Firstly, the fuzzification of the Saaty's scale (the AHP method) is carried out in order to obtain weight coefficients of the criteria. The main advantage of this fuzzification consists in its treating the uncertainties that may arise as a result of the uncertainty of the decision-makers about the comparisons they make. Secondly, the fuzzification of the MABAC method is performed in order to present the values of the alternatives by the criteria in the most realistic form. Accordingly, the paper is sectioned in four parts. The first gives the description of the problem to be solved; the second presents the methods determining the hybrid model; in the third, the criteria are considered and their weight coefficients are calculated (using the FAHP method), while the fourth shows the application of the FMABAC method to a specific example.

The main objective of the paper is to improve the decision-making processes in the Serbian Army, more precisely, to improve the processes of selecting locations for overcoming water barriers, by tanks with a deep wading technique. The process itself can be improved at two levels. Firstly, by defining the criteria that the choice to be made is based on, and secondly, by defining the methodology according to which this choice is implemented.

2. Problem description

The military personnel who command and manage units are liable to come across, in their work, many situations where making significant decisions is needed, especially during combat operations. In these situations, wrong decisions can result in losses of human lives and material resources. Therefore, in the military organization, special attention is given to the decision-making process because a human being is in the center of every decision, and, moreover, all the people are not expected to react in the same way in the situations in which they may find themselves (Pamučar et al., 2011a). For this reason, the application of a multi-criteria decision-making is an inevitable tool in supporting a decision-making process. In this paper, several methods are applied, FAHP and FMABAC, to improve and facilitate a decision-making process when selecting a location at the water barrier for deep wading by tanks.

Crossing water barriers by tanks can be realized in a number of ways: by a wading, by a deep wading, by floating on the water (if a tank possesses amphibious characteristics) and by underwater driving (*Driving manual for tanks and armored vehicles*, 1971). The way of overcoming the obstacle shall depend on the situation and the characteristics of technical resources. For deep wading which is discussed in this paper, special preparation of tanks, stuff and crossing points need to be carried out.

The phrase 'location for deep wading as a technique of crossing the river by tanks' implies the location for crossing a water barrier (rivers, canals, lakes and the like) at the maximum water depth of up to 1.80 m and the flow rate of up to 1.5 m/sec, considering that the bottom of the river is suitable (*The military lexicon*, 1981; *Tank M-84, description, handling, basic and technical maintenance*, 1988). At the river having the width of up to 200 m, the location of crossing is at least 25 m wide, and if the river is over 200 m wide, the width is 40-50 m (*Tank M-84, description, handling, basic and technical maintenance*, 1988). The entrance and exit ramps are set at the crossing point and the control service is formed (*Tank M-84, description, handling, basic and technical maintenance*, 1988). This is organized at special locations which must meet certain conditions.

Modern tanks are made in order to perform a deep wading operation when overcoming water barriers, with the basic aim of reducing negative impacts of water obstacles and creating conditions for an uninterrupted operation. The Serbian Army is equipped with the tank M-84 - a crawler vehicle with powerful weapon, strong armor protection and great maneuverability and passability (*The military lexicon*, 1981).

In the literature are outlined some criteria that the crossing points should meet, but without any precise definitions. Such an approach makes it inevitable that decision-making about selecting the crossing point relies on the experience and knowledge of decision-makers and their associates in the specific situation. In other words, a situation could also occur in which the decision-makers would not have enough knowledge and experience for choosing such a crossing point. Deciding on the selection of a place for organizing deep wading by tanks is performed by ranking the offered locations (alternatives) and selecting the best location for crossing over.

3. Description of the methods applied

In the following part of the paper triangular fuzzy numbers in the shortest terms are described. The basic principles of fuzzy logic and fuzzy numbers, as well as of the AHP method, are not explained because their description is provided in a large number of papers (Saaty, 1980; Teodorović & Kikuchi, 1994; Čupić & Suknović, 2010; Pamučar et al., 2011a; Devetak & Terzić, 2011). They also provide a detailed fuzzification of the Saaty's scale, with an overview of different approaches to fuzzification, and the fuzzification of the MABAC method.

The basic phases with the model steps are shown in Fig. 1.

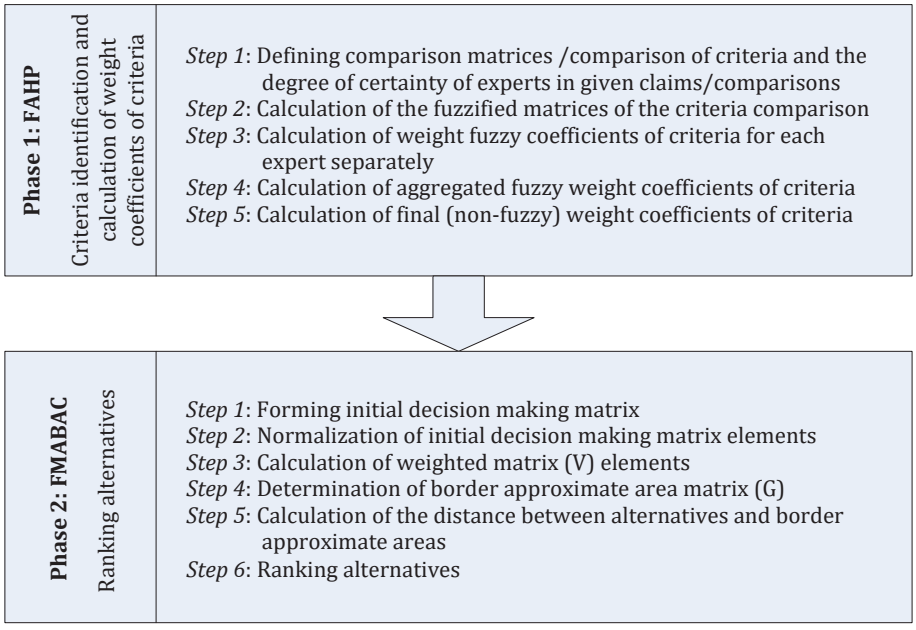

Figure 1. FAHP-FMABAC model

3.1 Triangular fuzzy numbers

The fuzzification of the MABAC method is performed by using triangular fuzzy numbers. A general form of the triangular fuzzy number is given in Fig. 2.

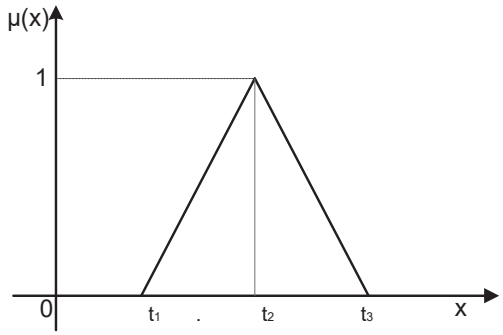

Figure 2. Triangular fuzzy number

Triangular fuzzy numbers have the form $\tilde{T}=(t_1,t_2,t_3)$. Value t_1 represents the left distribution of the confidence interval of fuzzy number T, t_2 is where the fuzzy number membership function has the maximum value - equal to 1, and t_3 represents the right distribution of the confidence interval of fuzzy number $\tilde{T}$ (Pamučar, 2011). The membership function of fuzzy number T is defined with the following expressions:

$$\mu_{\tilde{T}}(x)=\begin{cases}0, & x<t_1\\ \dfrac{x-t_1}{t_2-t_1}, & t_1\le x\le t_2\\ 1, & x=t_2\\ \dfrac{t_3-x}{t_3-t_2}, & t_2\le x\le t_3\\ 0, & x>t_3\end{cases} \tag{1}$$

For a final, operational role, most often it is necessary to perform defuzzification of the fuzzy number in order to obtain a crisp value. For the defuzzification of fuzzy numbers the following expressions are mostly used (Seiford, 1996):

$$\text{defazzy } S=\left[(t_3-t_1)+(t_2-t_1)\right]3^{-1}+t_1 \tag{2}$$

$$\text{defazzy } S=\left[\lambda t_3+t_2+(1-\lambda)t_1\right]2^{-1} \tag{3}$$

where λ represents optimism index $\lambda\in[0,1]$. Optimism index (λ) is described as a belief of the decision-makers in a decision-making risk. The most commonly used values are 0, 0.5 and 1 which are used to represent a pessimistic, moderate and optimistic attitude towards risk (Milićević, 2014).

3.2. Fuzzy AHP method - Fuzzification of the Saaty's scale

The Analytical Hierarchical Process is a method often used in multi-criteria decision-making. This method was developed by Thomas Saaty. It is based on the development of a complex problem into the hierarchy scheme, with the aim at the top, criteria, sub-criteria and alternatives at the levels and sublevels of the hierarchy scheme (Saaty, 1980), Fig. 3.

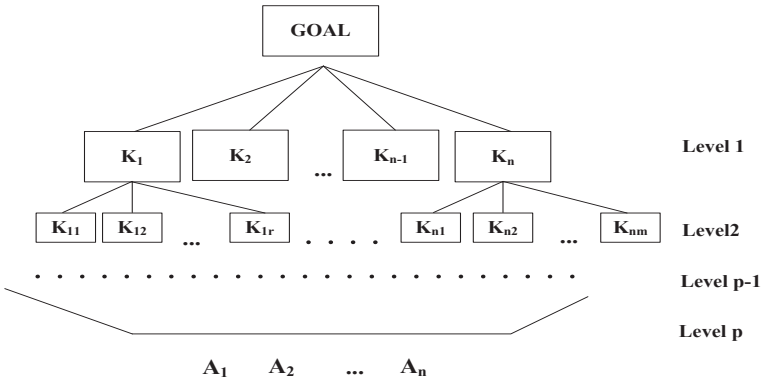

Figure 3. General hierarchical model in AHP

To compare the criteria in pairs, the Saaty's scale is commonly used (Table 1), which is considered a standard for the AHP method.

Table 1. Saaty's scale for a comparison in pairs

Standard values	Definition	Inverse values
1	The same importance	1
3	Weak dominance	1/3
5	Strong dominance	1/5
7	Very strong dominance	1/7
9	Absolute dominance	1/9
2, 4, 6, 8	Intervalues	1/2, 1/4, 1/6, 1/8

So far, the Saaty's scale has been fuzzified in various ways. The simplest Saaty's scale fuzzification is done by using fuzzy numbers with a predetermined confidence interval. In such fuzzification, the confidence intervals of fuzzy numbers are first established followed by the comparison in pairs. This approach to fuzzification can also be called a "sharp" fuzzification (Božanić et al., 2015b). Unlike "sharp" fuzzification, a "soft" fuzzification assumes that the confidence interval is not predetermined, but it is defined during the decision-making process based on additional parameters (Božanić & Pamučar, 2016).

Laarhoven and Pedrycz carried out one of the earliest fuzzifications of the Saaty's scale in 1983 (John et al., 2014). Nowadays, many papers can be found handling this topic. In Table 2 are given the examples of the most commonly defined left and right distribution of fuzzy numbers.

Table 2. The Saaty's scale for comparison in pairs using fuzzy numbers with a predetermined confidence interval

Definition	Standard values	Fuzzification in Kilic et al. (2014), John et al. (2014), Li et al. (2009)	Fuzzification in Kamvysi et al. (2014), Meng et al. (2014)
The same importance	1	(1,1,1)	(1,1,1)
Weak dominance	3	(2,3,4)	(2,3,4)
Strong dominance	5	(4,5,6)	(4,5,6)
Very strong dominance	7	(6,7,8)	(6,7,8)
Absolute dominance	9	(8,9,9)	(8,9,10)
Intervalues	2, 4, 6, 8	(x-1, x, x+1)	(x-1, x, x+1)

It frequently occurs that, instead of the classic Saaty's scale, a scale based on the same principles as Saaty's is used, but with fewer comparison values (seven, six or five), as presented in Martinovic & Simon (2014), Carnero (2014), Bozbura et al. (2007), Isaai et al. (2011), Deng et al. (2014) Junior et al. (2014). Regardless of the number of comparisons, they all define the confidence interval in the same way [x-1, x, x + 1], where x presents a standard comparison value.

In Refs. Srđević et al. (2008), Gardašević-Filipović & Šaletić (2010), Janacković et al. (2013), Janjić et al. (2014), the Saaty's scale is modified so that the differences between t_2 and t_1, respectively t_3 and t_2, are not the same for every standard value (Table 3), as has happened in most of the previous cases. Value "δ" is obtained from interval $0.5 \leq \delta \leq 2$ (Srđević et al., 2008).

Table 3. Saaty's scale for comparison in pairs with different confidence interval of a fuzzy number (Srđević et al., 2008; Gardašević-Filipović & Šaletić, 2010; Janacković et al., 2013; Janjić et al., 2014)

Definition	Standard values	Fuzzy number
The same importance	1	(1, 1, 1)
Weak dominance	3	(3-δ, 3, 3+δ)
Strong dominance	5	(5-δ, 5, 5+δ)
Very strong dominance	7	(7-δ, 7, 7+δ)
Absolute dominance	9	(9-δ, 9, 9+δ)
Intervalues	2,4,6,8	(x-δ, x, x+δ), x=2,4,6,8

The references cited where fuzzifications of the modified scales are performed represent only a minor part of this topic. The authors often use other types of functions, such as trapezoidal functions, Gaussian functions, and in addition to classic, also interval fuzzy numbers (Abdullah & Najib, 2014; Kahraman et al., 2014) etc. The number of values the scale contains for comparison in pairs coincides with the results of psychological experiments which showed that an individual could not simultaneously compare more than 7 ± 2 objects (Miler, 1956).

A different ("soft") approach is presented in papers by Božanić et al. (2011, 2013), Pamučar et al. (2011b, 2012, 2015). In these fuzzifications, the confidence interval of a fuzzy number remains open, or dependent on the person who performs the comparison in pairs. The new parameter - the degree of uncertainty "β" - is introduced into the calculation of the confidence interval, where under the value "$\beta = 0$" is described the highest possible uncertainty, while the value "$\beta = 1$" corresponds to the situation in which with the fullest certainty is known which linguistic expression corresponds to the given comparison. Parameter β uses the values from the interval [0, 1]. The presentation of the fuzzified Saaty's scale used in the papers mentioned is given in Table 4.

Table 4. The fuzzification of the Saaty's scale by applying the degree of uncertainty (Božanić et al., 2011, 2013; Pamučar et al., 2011b, 2012, 2015)

Definition	Standard values	Fuzzy number
The same importance	1	$(1, 1, 1)$
Weak dominance	3	$(3\beta, 3, (2-\beta)3)$
Strong dominance	5	$(5\beta, 5, (2-\beta)5)$
Very strong dominance	7	$(7\beta, 7, (2-\beta)7)$
Absolute dominance	9	$(9\beta, 9, 9)$
Intervalues	2, 4, 6, 8	$(x\beta, x, (2-\beta)x),$ $x = 2,\ 4,\ 6,\ 8$

This approach to fuzzification is particularly important in group decision-making since it can be expected that parameter β differs from one to another decision-maker/analyst/expert (DM/A/E). Consequently, the confidence interval of the fuzzy numbers varies from one to another decision-maker/analyst (Božanić & Pamučar, 2016).

In order to determine the weight coefficients in this paper the fuzzification shown in Božanić & Pamučar (2016), Božanić et al. (2015a, 2016b), Pamučar et al. (2016) is used. In this fuzzification, several questions are raised, namely, whether DM/A/Es are certain about the statements on comparison in pairs, how certain they are about such statements, and whether they are equally certain about every statement. The situation in which a DM/A/E is not sure how to evaluate the relationship between two elements is not rare because the classic Saaty's scale is subjective to some extent. Its elements are not precisely explained, which in certain situations can cause some confusion; this, however, does not imply that the Saaty's scale is bad, only that there is a wide range of options to upgrade and improve it (Božanić & Pamučar, 2016).

This fuzzification proceeds from two elements: 1) the introduction of fuzzy numbers instead of classic numbers of the Saaty's scale, 2) the introduction of the degree of certainty of decision-makers/analysts in the statements they give during comparison in pairs - γ (Božanić & Pamučar, 2016). The basis of the fuzzification is in the assumption that DM/A/Es can have a different degree of certainty γ_{ji} in the accuracy of the comparison in pairs, so it is allowed for the degree of certainty to differ from one to another comparison pair. The value of the degree of certainty is within the interval $\gamma \in [0,1]$. In cases where $\gamma_{ji}=0$, DM/A/Es are considered not to have

any knowledge on the basis of which the comparison can be made, so in such relationship it is defined $a_{ji}=1$. The value of the degree of certainty $\gamma=1$ describes the absolute certainty of DM/A/E in the defined comparison. The overview of a fuzzy number with different degrees of certainty is given in Fig. 4. As an example, it is taken a weak-dominance value from the Saaty's scale and the degrees of certainty $\gamma=1$, $\gamma=0.8$ and $\gamma=0.4$.

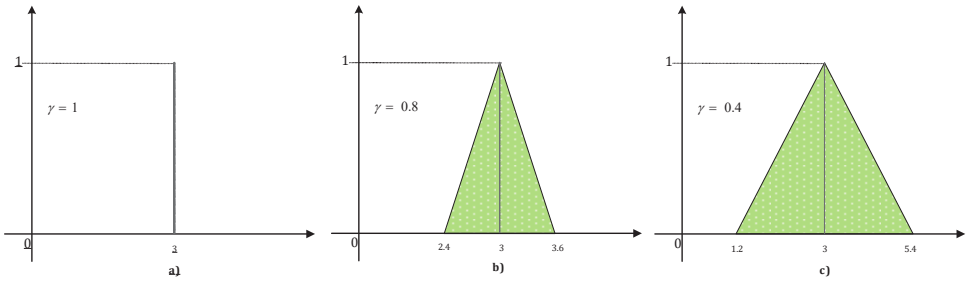

Figure 4. Dependence of the fuzzy number on the degree of certainty (Božanić & Pamučar, 2016)

There are different methods for defining the degree of certainty. This value can be defined in percentages or by using fuzzy linguistic descriptors. In the first case, experts would define the percentage of certainty in comparison in pairs (from 0 to 100%). In the second case, defining of the degree of certainty would be done using fuzzy linguistic descriptors. An example of the fuzzy linguistic descriptor for determining the degree of certainty which is used in this paper is given in Fig. 5.

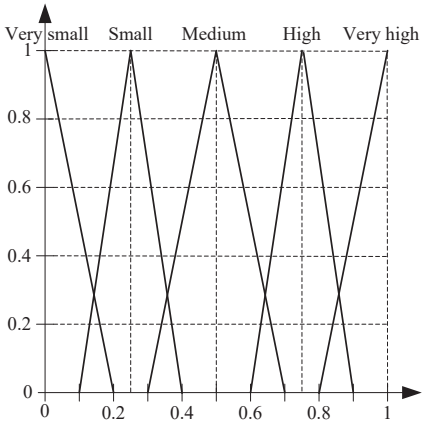

Figure 5. Fuzzy linguistic descriptors for evaluating the degree of certainty of experts

As can be seen in Fig. 5, the degree of certainty of DM/A/Es is defined with five linguistic variables: VS - very small, S - small, M - medium, H - high and VH - very high.

The degree of certainty γ is used to define the confidence interval of fuzzy numbers when modifying the Saaty's scale, as shown in Table 5.

Table 5. Fuzzification of the Saaty's scale using the degree of certainty

Definition	Standard values	Fuzzy number	Inverse values fuzzy number
The same importance	1	(1, 1, 1)	(1, 1, 1)
Weak dominance	3	$\left(3\gamma_{ji}, 3, \left(2-\gamma_{ji}\right)3\right)$	$\left(1/(2-\gamma_{ji})3, 1/3, 1/3\gamma_{ji}\right)$
Strong dominance	5	$\left(5\gamma_{ji}, 5, \left(2-\gamma_{ji}\right)5\right)$	$\left(1/(2-\gamma_{ji})5, 1/5, 1/5\gamma_{ji}\right)$
Very strong dominance	7	$\left(7\gamma_{ji}, 7, \left(2-\gamma_{ji}\right)7\right)$	$\left(1/(2-\gamma_{ji})7, 1/7, 1/7\gamma_{ji}\right)$
Absolute dominance	9	$\left(9\gamma_{ji}, 9, \left(2-\gamma_{ji}\right)9\right)$	$\left(1/(2-\gamma_{ji})9, 1/9, 1/9\gamma_{ji}\right)$
Intervalues	2, 4, 6, 8	$\left(x\gamma_{ji}, x, \left(2-\gamma_{ji}\right)x\right)$ $x = 2,\ 4,\ 6,\ 8$	$\left(1/\left(2-\gamma_{ji}\right)x, 1/x, 1/x\gamma_{ji}\right)$ $x = 2,\ 4,\ 6,\ 8$

By defining different values of parameter γ_{ji} , the left and right distribution of fuzzy numbers change from one comparison to another, according to the expression:

$$T = \left(t_1, t_2, t_3\right) = \begin{Bmatrix} t_1 = \gamma t_2, & t_1 \le t_2, & t_1, t_2 \in \left[1/9, 9\right] \\ t_2 = t_2, & & t_2 \in \left[1/9, 9\right] \\ t_3 = \left(2-\gamma\right)t_2, & t_3 \le t_2, & t_2, t_3 \in \left[1/9, 9\right] \end{Bmatrix} \tag{4}$$

t_2 value represents the value of the linguistic expression from the classic Saaty's scale, in which the fuzzy number has its maximum membership $t_2 = 1$.

Fuzzy number $T = \left(t_1, t_2, t_3\right) = \left(x\gamma, x, \left(2-\gamma\right)x\right)$, $x \in \left[1, 9\right]$ is defined with expressions:

$$t_1 = x\gamma = \begin{cases} x\gamma, & \forall\ 1 \le x\gamma \le x \\ 1, & \forall\ x\gamma < 1 \end{cases} \tag{5}$$

$$t_2 = x,\ \forall\ x \in \left[1, 9\right] \tag{6}$$

$$t_3 = \left(2-\gamma\right)x, \forall x \in \left[1, 9\right] \tag{7}$$

Inverse fuzzy number $T^{-1} = \left(1/t_3, 1/t_2, 1/t_1\right) = \left(1/\left(2-\gamma\right)x, 1/x, 1/\gamma x\right)$, $x \in \left[1, 9\right]$ is defined as:

$$1/t_3 = 1/\left(2-\gamma\right)x = \begin{cases} 1/\left(2-\gamma\right)x, & \forall\ 1/\left(2-\gamma\right)x < 1 \\ 1, & \forall\ 1/\left(2-\gamma\right)x \ge 1 \end{cases}, x \in \left[1, 9\right] \tag{8}$$

$$1/t_2 = 1/x,\ \forall\ 1/x \in \left[1, 9\right] \tag{9}$$

$$1/t_1 = 1/\gamma x, \forall 1/x \in \left[1, 9\right] \tag{10}$$

By using the previously defined scale, the decision makers/analysts enter the values of the criteria compared in pairs into a new, modified matrix:

$$A = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} a_{11};\gamma_{11} & a_{12};\gamma_{12} & \cdots & a_{1n};\gamma_{1n} \\ a_{21};\gamma_{21} & a_{22};\gamma_{22} & \cdots & a_{2n};\gamma_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1};\gamma_{n1} & a_{n2};\gamma_{n2} & \cdots & a_{nn};\gamma_{nn} \end{bmatrix} \end{array} \tag{11}$$

where $\gamma_{ji}=\gamma_{ij}$. In the same way, the alternatives are compared in pairs. The standard steps of the AHP method are further applied. After all the calculations have been completed, the fuzzy values of the criteria functions are obtained by every alternative observed, where defuzzification is performed using expression (2) or (3).

The scale shown can be applied in the classic AHP method, where the weight coefficients are first calculated, and then the evaluation of the criteria functions for every observed alternative is made. The scale is also suitable for evaluating the weight of criteria for later application of other methods (TOPSIS, VIKOR, etc.).

The defined scale is also suitable for the process of group decision-making, which has recently shown the tendency of being used more and more. Experts' incorporation significantly improves the quality of decisions made because knowledge and experience are gathered and integrated into one whole. The most commonly used approach in collecting data from experts is the Delphi method (Mučibabić, 2003). The scale defined in this paper in group decision-making is applied as well as the standard AHP method.

3.3. Fuzzy MABAC method

The MABAC method is developed by Pamučar & Ćirović (2015). The basic setting of the MABAC method consists in defining the distance of the criteria function of every observed alternative from the border approximate area. The MABAC method was modified with several papers. Roy et al. (2017) extended the MABAC method using rough numbers. Xue et al. (2016) defined an interval-valued intuitionistic fuzzy MABAC approach. Yu et al. (2017) and Roy et al. (2016) modified MABAC approach with interval type-2 fuzzy numbers. Peng and Yang (2016) developed Pythagorean Fuzzy Choquet Integral Based MABAC Method.

The following text shows the procedure for implementing the fuzzificated MABAC method (with triangular fuzzy number) in seven steps, i.e., its mathematical formulation.

Step 1. Forming of the initial decision matrix ($\tilde{X}$). In the first step the evaluation of m alternatives by n criteria is performed. The alternatives are shown by vectors $A_i = (\tilde{x}_{i1}, \tilde{x}_{i2} ..., \tilde{x}_{in})$, where x_{ij} is the value of the *i* alternative by *j* criterion (i = 1,2, ... m; j = 1,2, ..., n).

$$\tilde{X} = \begin{array}{c} \\ A_1 \\ A_2 \\ \cdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \ldots & \tilde{x}_{1n} \\ \tilde{x}_{11} & \tilde{x}_{22} & & \tilde{x}_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ \tilde{x}_{1m} & \tilde{x}_{2m} & \ldots & \tilde{x}_{mn} \end{bmatrix} \end{array} \tag{12}$$

where *m* denotes the number of the alternatives, and *n* denotes total number of criteria.

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

$$\tilde{N} = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \dots & \tilde{t}_{1n} \\ \tilde{t}_{11} & \tilde{t}_{22} & & \tilde{t}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{t}_{1m} & \tilde{t}_{2m} & \dots & \tilde{t}_{mn} \end{bmatrix} \end{array} \tag{13}$$

The elements of the normalized matrix ($\tilde{N}$) are obtained by using the expressions:

For benefit-type criteria

$$\tilde{t}_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{14}$$

For cost-type criteria

$$\tilde{t}_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{15}$$

where x_{ij}, x_i^+ and x_i^- represent the elements of the initial decision matrix ($\tilde{X}$), whereby x_i^+ and x_i^- are defined as follows:

$x_i^+ = \max(x_{1r}, x_{2r}, ..., x_{mr})$ and represent the maximum values of the right distribution of fuzzy numbers of the observed criterion by alternatives.

$x_i^- = \min(x_{1l}, x_{2l}, ..., x_{ml})$ and represents minimum values of the left distribution of fuzzy numbers of the observed criterion by alternatives

Step 3. Calculation of the weighted matrix ($\tilde{V}$) elements

$$\tilde{V} = \begin{bmatrix} \tilde{v}_{11} & \tilde{v}_{12} & \dots & \tilde{v}_{1n} \\ \tilde{v}_{21} & \tilde{v}_{22} & \dots & \tilde{v}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{v}_{ml} & \tilde{v}_{m2} & \dots & \tilde{v}_{mn} \end{bmatrix} \tag{16}$$

The elements of the weighted matrix ($\tilde{V}$) are calculated on the basis of the expression (17)

$$\tilde{v}_{ij} = w_i \bullet \tilde{t}_{ij} + w_i \tag{17}$$

where $\tilde{t}_{ij}$ represent the elements of the normalized matrix ($\tilde{N}$), w_i represents the weighted coefficients of the criterion.

Step 4. Determination of the approximate border area matrix ($\tilde{G}$). The border approximate area for every criterion is determined by the expression (18):

$$\tilde{g}_i = \left(\prod_{j=1}^{m} \tilde{v}_{ij} \right)^{1/m} \tag{18}$$

where $\tilde{v}_{ij}$ represent the elements of the weighted matrix ($\tilde{V}$), m represents total number of alternatives.

After calculating the value of $\tilde{g}_i$ by criteria, a matrix of border approximate areas $\tilde{G}$ is developed in the form *n* x 1 (*n* represents total number of criteria by which the selection of the offered alternatives is performed).

$$\tilde{G} = \begin{matrix} C_1 & C_2 & \dots & C_n \\ [\tilde{g}_1 & \tilde{g}_2 & \dots & \tilde{g}_n] \end{matrix} \tag{19}$$

Step 5. Calculation of the matrix elements of alternatives distance from the border approximate area ($\tilde{Q}$)

$$\tilde{Q} = \begin{bmatrix} \tilde{q}_{11} & \tilde{q}_{12} & \dots & \tilde{q}_{1n} \\ \tilde{q}_{21} & \tilde{q}_{22} & & \tilde{q}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{q}_{m1} & \tilde{q}_{m2} & \dots & \tilde{q}_{mn} \end{bmatrix} \tag{20}$$

The distance of the alternatives from the border approximate area ($\tilde{q}_{ij}$) is defined as the difference between the weighted matrix elements ($\tilde{V}$) and the values of the border approximate areas ($\tilde{G}$).

$$\tilde{Q} = \tilde{V} - \tilde{G} \tag{21}$$

The values of alternative $\tilde{A}_i$ may belong to the border approximate area ($\tilde{G}$), to the upper approximate area ($\tilde{G}^+$), or to the lower approximate area ($\tilde{G}^-$), i.e., $\tilde{A}_i \in \left\{ \tilde{G} \vee \tilde{G}^+ \vee \tilde{G}^- \right\}$. The upper approximate area ($\tilde{G}^+$) represents the area in which the ideal alternative is found (A^+), while the lower approximate area ($\tilde{G}^-$) represents the area where the anti-ideal alternative is found (A^-), as presented in the Fig. 6.

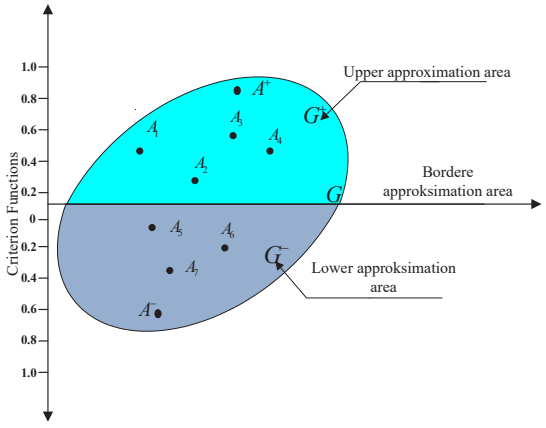

Figure 6. Display of upper ($\tilde{G}^+$), lower ($\tilde{G}^-$) and border (G) approximate area (Pamučar & Ćirović, 2015)

The membership of alternative $\tilde{A}_i$ to the approximate area ($G, \tilde{G}^+$ or $\tilde{G}^-$) is determined by the expression

$$\tilde{A}_i \in \begin{cases} \tilde{G}^+ \text{ if } \tilde{q}_{ij} > 0 \\ \tilde{G} \text{ if } \tilde{q}_{ij} = 0 \\ \tilde{G}^- \text{ if } \tilde{q}_{ij} < 0 \end{cases} \quad (22)$$

For alternative $\tilde{A}_i$ to be chosen as the best from the set, it is necessary for it to belong, by as many as possible criteria, to the upper approximate area ($\tilde{G}^+$). The higher the value $\tilde{q}_i \in \tilde{G}^+$ indicates that the alternative is closer to the ideal alternative, while the lower the value $\tilde{q}_i \in \tilde{G}^-$ indicates that the alternative is closer to the anti-ideal alternative.

Step 6. Ranking of alternatives. The calculation of the values of the criteria functions by alternatives is obtained as the sum of the distance of alternatives from the border approximate areas ($\tilde{q}_i$). By summing up the matrix $\tilde{Q}$ elements per rows, the final values of the criteria function of alternatives are obtained

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{q}_{ij}, \; j = 1, 2, \ldots, n, \; i = 1, 2, \ldots, m \quad (23)$$

where *n* represents the number of criteria, and *m* is the number of alternatives.

Step 7 Final ranking of alternatives. By defuzzification of the obtained values $\tilde{S}_i$, the final rank of alternatives is obtained. The defuzzification can be performed with the expressions (2) or (3).

4. Criteria description and definition of weight coefficients

The criteria for selecting the most convenient locations for organizing deep wading as a river crossing technique by tanks are defined by an analysis of the available literature. The most detailed description of the conditions that the tanks' crossing point should meet is provided in (Pifat, 1980).

Applying a detailed analysis, seven key criteria are distinguished, namely:

C_1 - Water barrier width represents the distance from one river bank to the other, measured by the surface of the water. When crossing the water barrier, the width affects the speed of crossing over, i.e., the time the unit would be exposed to enemy fire;

C_2 - Composition of the bottom-stream bed implies the composition of the river bottom in the geological sense. The type and composition of the bottom has a major or even decisive influence on the possibility of deep wading performance on rivers and canals. A hard, rocky but flat bottom, or the bottom with stable, solid gravel allows the crossing without any prior works, while a soft, muddy or uneven bottom requires greater workloads to reinforce bottom of the river, or it can completely disable crossing over a barrier with this technique;

C_3 - Influence of the enemy means that the crossing location should provide the least impact of the enemy on crossing over water barrier.

C_4 - Water flow speed refers to water flowing expressed in the unit of time. The speed of the water flow affects drift sideways of the vehicles that cross over the water barrier;

C_5 - Characteristics of the river bank imply the existence, quality and condition of access roads, composition of the ground on the river bank, height of the bank, slope of the bank, forestation, artificial obstacles, etc. The extent of the work necessary to take on the arrangement of the bank depends on these characteristics;

C_6 - Water barrier depth is the distance measured from the water surface to the bottom of the barrier. The maximum water depth at which it is possible to perform river crossing by tanks with a deep wading technique is 1.8 m.

C_7 - Masking implies that the site where a deep wading, as a technique of crossing by tanks, will be organized must provide good concealment of the access to the bank and to the water barrier, as well as good masking conditions on the bank in situations where the crossing is stopped (due to the effects of the air force, etc.). The complexity of making a mask also plays an important role.

Criteria C_1, C_4 and C_6 are numeric, while criteria C_2, C_3, C_5 and C_7 are linguistic. The values of the linguistic criteria are described with fuzzy linguistic descriptors, as presented in the Fig. 7.

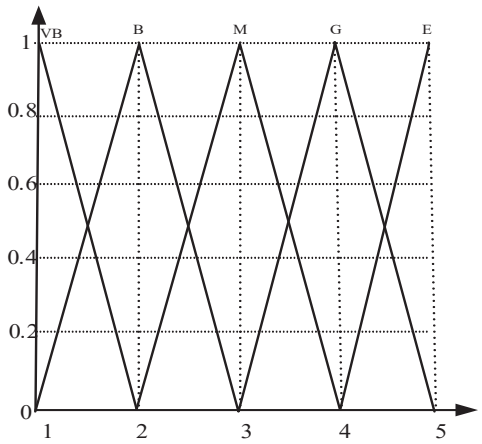

Figure 7. Graphic display of fuzzy linguistic descriptors (Božanić et al., 2016a)

Every criterion can be described with five values: VB – very bad, B – bad, M – medium, G – good and E – excellent.

After the key criteria have been defined, the conditions are created for their comparison in pairs. The comparison in pairs is conducted by 11 experts using the Saaty's scale. Also, the experts define the degree of certainty in the comparisons they make using fuzzy linguistic descriptors shown in Fig. 5. The comparison in pairs and the degree of certainty form the initial decision matrix. The first expert defines the following elements of the initial decision matrix:

$$A = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \end{array} \begin{array}{c} \begin{array}{ccccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 \end{array} \\ \begin{bmatrix} 1;- & 2;H & 2;VH & 2;M & 3;H & 3;H & 4;S \\ 1/2;H & 1;- & 1/3;M & 4;H & 2;VH & 3;VH & 2;H \\ 1/2;VH & 3;M & 1;- & 2;VS & 1;H & 2;S & 2;H \\ 1/2;M & 1/4;H & 1/2;VS & 1;- & 1/2;VH & 2;H & 1/3;M \\ 1/3;H & 1/2;VH & 1;H & 2;VH & 1;- & 3;VH & 1/3;H \\ 1/3;H & 1/3;VH & 1/2;S & 1/2;H & 1/3;VH & 1;- & 1/2;VH \\ 1/4;S & 1/2;H & 1/2;H & 3;M & 3;H & 2;VH & 1;- \end{bmatrix} \end{array}$$

When fuzzy linguistic descriptors are defuzzified, the following matrix is obtained:

$$A` = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \end{array} \begin{array}{c} \begin{array}{ccccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 \end{array} \\ \begin{bmatrix} 1;- & 2;0.75 & 2;0.933 & 2;0.5 & 3;0.75 & 3;0.75 & 4;0.25 \\ 1/2;0.75 & 1;- & 1/3;0.5 & 4;0.75 & 2;0.933 & 3;0.933 & 2;0.75 \\ 1/2;0.933 & 3;0.5 & 1;- & 2;0.067 & 1;0.75 & 2;0.25 & 2;0.75 \\ 1/2;0.5 & 1/4;0.75 & 1/2;0.067 & 1;- & 1/2;0.933 & 2;0.75 & 1/3;0.5 \\ 1/3;0.75 & 1/2;0.75 & 1;0.75 & 2;0.933 & 1;- & 3;0.933 & 1/3;0.75 \\ 1/3;0.75 & 1/3;0.933 & 1/2;0.25 & 1/2;0.75 & 1/3;0.933 & 1;- & 1/2;0.933 \\ 1/4;0.25 & 1/2;0.75 & 1/2;0.75 & 3;0.5 & 3;0.75 & 2;0.933 & 1;- \end{bmatrix} \end{array}$$

The next step is the calculation of a fuzzified initial decision-making matrix using the expressions given in Table 5:

$$\tilde{A}` = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & \ldots & C_6 & C_7 \end{array} \\ \begin{bmatrix} (1,1,1) & (1.5,2,2.5) & \ldots & (2.25,3,3.75) & (1,4,7) \\ (0.4,0.5,0.67) & (1,1,1) & \ldots & (2.8,3,3.2) & (1.5,2,2.5) \\ (0.47,0.5,0.54) & (1,5,3,4.5) & \ldots & (1,2,3.5) & (1.5,2,2.5) \\ (0.33,0.5,1) & (0.2,0.25,0.33) & \ldots & (1.5,2,2.5) & (0.22,0.33,0.67) \\ (0.27,0.33,0.44) & (0.47,0.5,0.54) & \ldots & (2.8,3,3.2) & (0.27,0.33,0.44) \\ (0.27,0.33,0.44) & (0.31,0.33,0.36) & \ldots & (1,1,1) & (0.47,0.5,0.54) \\ (0.14,0.25,1) & (0.4,0.5,0.67) & \ldots & (1.87,2,2.13) & (1,1,1) \end{bmatrix} \end{array}$$

Applying standard steps of the AHP method, the values of the weight coefficients of criteria for the first expert are obtained, and shown in Table 6.

Table 6. Weight coefficients of criteria for the first expert

Criterion	Fuzzy weight coefficient of criteria	Weight coefficient of criteria (FAHP)	Weight coefficient of criteria (classic AHP)
C_1	(0.145,0.271,0.487)	0.269	0.271
C_2	(0.108,0.169,0.280)	0.166	0.169
C_3	(0.094,0.181,0.344)	0.184	0.181
C_4	(0.043,0.077,0.153)	0.081	0.077
C_5	(0.081,0.112,0.157)	0.104	0.112
C_6	(0.036,0.058,0.099)	0.057	0.058
C_7	(0.077,0.133,0.258)	0.139	0.133

After the aggregation of the weight coefficients of criteria of all experts, the final weight coefficients of the criteria are obtained, which is shown in Table 7.

Table 7. Final weight coefficients of the criteria

Criterion	Weight coefficient of criteria (FAHP)	Weight coefficient of criteria (classic AHP)
C_1	0.243	0.262
C_2	0.159	0.169
C_3	0.182	0.194
C_4	0.097	0.079
C_5	0.125	0.109
C_6	0.071	0.055
C_7	0.123	0.132

The analysis of the results from Tables 6 and 7 points to the existence of differences between the application of the standard and the fuzzified Saaty's scale. Small differences in values indicate that, when applying the fuzzified scale, the value assigned for comparison in pairs is still a key element. The degree of certainty makes only certain corrections of these comparisons.

5. Ranging alternatives - applying the fuzzy MABAC method

The application of the fuzzy MABAC method is presented by illustrated alternatives. Further in the paper are ranked six alternatives. In the first step, the initial decision matrix ($\tilde{X}$) is defined.

$$\tilde{X} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \end{array} \begin{array}{c} C_1 \\ \left[\begin{array}{c} (115,120,126) \\ (134,140,147) \\ (105,110,115) \\ (120,125,130) \\ (153,160,170) \\ (114,118,126) \end{array}\right. \end{array} \begin{array}{c} C_2 \\ \begin{array}{c} G \\ E \\ E \\ M \\ G \\ M \end{array} \end{array} \begin{array}{c} C_3 \\ \begin{array}{c} E \\ M \\ G \\ VB \\ E \\ M \end{array} \end{array} \begin{array}{c} C_4 \\ \begin{array}{c} (0.9,1.1,1.3) \\ (0.7,0.9,1.2) \\ (1.05,1.2,1.4) \\ (0.8,1,1.2) \\ (0.6,0.7,0.8) \\ (1.1,1.15,1.25) \end{array} \end{array} \begin{array}{c} C_5 \\ \begin{array}{c} M \\ VB \\ E \\ G \\ E \\ G \end{array} \end{array} \begin{array}{c} C_6 \\ \begin{array}{c} (1.3,1.5,1.7) \\ (1.1,1.3,1.5) \\ (1.4,1.6,1.8) \\ (1.3,1.5,1.7) \\ (1,1.2,1.4) \\ (1.3,1.5,1.7) \end{array} \end{array} \begin{array}{c} C_7 \\ \left.\begin{array}{c} (1,1,2) \\ (3,4,5) \\ (2,3,4) \\ (1,1,2) \\ (3,4,5) \\ (2,3,4) \end{array}\right] \end{array}$$

Then the initial matrix is quantified:

$$\tilde{X} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \end{array} \begin{array}{c} C_1 \\ \left[\begin{array}{c} (115,120,126) \\ (134,140,147) \\ (105,110,115) \\ (120,125,130) \\ (153,160,170) \\ (114,118,126) \end{array}\right. \end{array} \begin{array}{c} C_2 \\ \begin{array}{c} (3,4,5) \\ (4,5,5) \\ (4,5,5) \\ (2,3,4) \\ (3,4,5) \\ (2,3,4) \end{array} \end{array} \begin{array}{c} C_3 \\ \begin{array}{c} (4,5,5) \\ (2,3,4) \\ (3,4,5) \\ (1,1,2) \\ (4,5,5) \\ (2,3,4) \end{array} \end{array} \begin{array}{c} C_4 \\ \begin{array}{c} (0.9,1.1,1.3) \\ (0.7,0.9,1.2) \\ (1.05,1.2,1.4) \\ (0.8,1,1.2) \\ (0.6,0.7,0.8) \\ (1.1,1.15,1.25) \end{array} \end{array} \begin{array}{c} C_5 \\ \begin{array}{c} (2,3,4) \\ (1,1,2) \\ (4,5,5) \\ (3,4,5) \\ (4,5,5) \\ (3,4,5) \end{array} \end{array} \begin{array}{c} C_6 \\ \begin{array}{c} (1.3,1.5,1.7) \\ (1.1,1.3,1.5) \\ (1.4,1.6,1.8) \\ (1.3,1.5,1.7) \\ (1,1.2,1.4) \\ (1.3,1.5,1.7) \end{array} \end{array} \begin{array}{c} C_7 \\ \left.\begin{array}{c} (1,1,2) \\ (3,4,5) \\ (2,3,4) \\ (1,1,2) \\ (3,4,5) \\ (2,3,4) \end{array}\right] \end{array}$$

In the second step, the normalization of the initial decision matrix elements is performed. For the normalization the expressions (14) and (15) are used. The results obtained are shown in the normalized matrix ($\tilde{N}$).

$$\tilde{N} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & \dots & C_6 & C_7 \end{array} \\ \begin{bmatrix} (0.68,0.77,0.85) & (0.33,0.67,1) & \dots & (0.13,0.38,0.63) & (0,0,0.25) \\ (0.35,0.46,0.55) & (0.67,1,1) & \dots & (0.38,0.63,0.88) & (0.5,0.75,1) \\ (0.85,0.92,1) & (0.67,1,1) & \dots & (0,0.25,0.5) & (0.25,0.5,0.75) \\ (0.62,0.69,0.77) & (0,0.33,0.67) & \dots & (0.13,0.38,0.63) & (0,0,0.25) \\ (0,0.15,0.26) & (0.33,0.67,1) & \dots & (0.5,0.75,1) & (0.5,0.75,1) \\ (0.68,0.8,0.86) & (0,0.33,0.67) & \dots & (0.13,0.38,0.63) & (0.25,0.5,0.75) \end{bmatrix} \end{array}$$

In the third step, the calculation of the weighted matrix ($\tilde{V}$) is performed by using the expression (17).

$$\tilde{V} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & \dots & C_6 & C_7 \end{array} \\ \begin{bmatrix} (0.41,0.43,0.45) & (0.21,0.27,0.32) & \dots & (0.08,0.1,0.12) & (0.12,0.12,0.15) \\ (0.33,0.36,0.38) & (0.27,0.32,0.32) & \dots & (0.10,0.12,0.13) & (0.18,0.22,0.25) \\ (0.45,0.47,0.49) & (0.27,0.32,0.32) & \dots & (0.07,0.09,0.11) & (0.15,0.18,0.22) \\ (0.39,0.41,0.43) & (0.16,0.21,0.27) & \dots & (0.08,0.1,0.12) & (0.12,0.12,0.15) \\ (0.24,0.28,0.31) & (0.21,0.27,0.32) & \dots & (0.11,0.12,0.14) & (0.18,0.22,0.25) \\ (0.41,0.44,0.45) & (0.16,0.21,0.27) & \dots & (0.08,0.1,0.12) & (0.15,0.18,0.22) \end{bmatrix} \end{array}$$

In the fourth step, the matrix of the approximate border areas ($\tilde{G}$) is obtained by using the expression (18).

$$\tilde{G} = \begin{array}{c} \begin{array}{ccccc} C_1 & & C_2 & \dots & C_6 & & C_7 \end{array} \\ \begin{bmatrix} (0.36,0.39,0.41) & (0.21,0.26,0.30) & \dots & (0.08,0.10,0.12) & (0.15,0.17,0.20) \end{bmatrix} \end{array}$$

The fifth step is the calculation of the matrix elements distance of the alternatives from the border approximate area ($\tilde{Q}$). The calculation is made by using the expression (21).

$$\tilde{Q} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & & C_2 & \dots & C_7 \end{array} \\ \begin{bmatrix} (0,0.04,0.08) & (-0.09,0,0.11) & \dots & (-0.08,-0.05,0) \\ (-0.08,-0.04,0.01) & (-0.03,0.06,0.11) & \dots & (-0.02,0.05,0.09) \\ (0.04,0.08,0.12) & (-0.03,0.06,0.11) & \dots & (-0.05,0.01,0.06) \\ (-0.02,0.02,0.07) & (-0.14,-0.05,0.06) & \dots & (-0.08,-0.05,0) \\ (-0.17,-0.11,-0.06) & (-0.09,0,0.11) & \dots & (-0.02,0.05,0.09) \\ (0,0.05,0.09) & (-0.14,-0.05,0.06) & \dots & (-0.05,0.01,0.06) \end{bmatrix} \end{array}$$

By summing up the elements of the matrix $\tilde{Q}$ per row, the final values of the criteria functions of alternatives are obtained, as presented in the Table 8.

Table 8. Fuzzy values of criteria functions of alternatives

Alternative	$\tilde{S}_i$
A_1	(-0.37,-0.10,0.25)
A_2	(-0.29,0.05,0.34)
A_3	(-0.20,0.14,0.40)
A_4	(-0.25,0.06,0.36)
A_5	(-0.32,-0.02,0.29)
A_6	(-0.31,0.04,0.36)

By defuzzification of the obtained values of the criteria functions of alternatives is obtained the rank of alternatives. In Table 9 are shown the results of alternatives ranking after the defuzzification, as well as the application of classic MABAC method and the results obtained by the survey of experts in the field of overcoming water barriers.

Table 9. Final values of the criteria function of alternatives

Alternative	Experts	Classic MABAC method		Defuzzification using the expression (2)	
		Si	Rank	Si	Rank
A_1	6	-0.098	6	-0.071	6
A_2	3	0.110	2	0.032	3
A_3	1	0.183	1	0.113	1
A_4	2	0.031	3	0.053	2
A_5	5	-0.024	5	-0.014	5
A_6	4	0.027	4	0.029	4

All the methods ranked the A_3 alternative at the first place, respectively, the alternatives A_5 and A_6 are found at the last two positions. Significant differences are noted in the ranking of alternatives A_2 and A_4, which change their rank depending on the method applied or its modification. Furthermore, by analyzing the outcome results it is noticed that the differences in the obtained values of the criteria functions of alternatives are less when the fuzzificated model is applied.

6. Conclusion

The paper presents a successful application of the hybrid model fuzzy AHP - fuzzy MABAC in the selection of the locations for river crossing by tanks with a deep wading technique . The comparison with the results obtained by an experts' survey, using the classic and the fuzzified MABAC method, leads to the conclusion that the fuzzified MABAC method can completely replace expert judgment. On the other hand, the application of the fuzzified AHP method in defining weight coefficients of the criteria takes into account uncertainty during comparison in pairs, which in relation to the classic AHP method, corrects the weight coefficients of the criteria.

The significance of the model is also reflected in the fact that the criteria for selecting locations for crossing over water barriers by tanks with a deep wading technique are defined. Also, these criteria are described in basic terms, which provides for a further possibility for their detailed elaboration.

The greatest contribution that the model presented in the paper makes lies in the fact that experience is, in a decision-making process, translated into mathematics. This makes the consideration of the problem more comprehensive and at the same time less dependent on the experience of decision-makers.

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