Decision Making: Applications in Management and Engineering
Vol. 2, Issue 1, 2019, pp. 132-146.
ISSN: 2560-6018
eISSN: 2620-0104
DOI:_ https://doi.org/10.31181/dmame1901132b

MULTI-CRITERIA FUCOM – FUZZY MABAC MODEL FOR THE SELECTION OF LOCATION FOR CONSTRUCTION OF SINGLE-SPAN BAILEY BRIDGE

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Received: 03 September 2018;
Accepted: 12 February 2019;
Available online: 09 March 2019.

Original scientific paper

Abstract: *Selecting the most favorable location for construction of single-span Bailey bridge is ideal for applying multi-criteria decision making. In that regard, it has been developed a model for selecting the most favorable location. The first part of the model is based on the full consistency method (FUCOM), and it is used for the evaluation of weight coefficients of criteria. The second part of the model presents the fuzzification of the Multi-Attributive Border Approximation Area Comparison (MABAC) method, which is used in the evaluation of alternatives. Additionally, in the paper are presented basic criteria, based on which the selection is to be made*

Key words: *FUCOM, fuzzy MABAC method, single-span Bailey bridge, selection of location.*

1. Introduction – problem description

The set for launching Bailey bridge consists of a number of elements used to make single-span and multi-span bridges (bridges on standing supports) which are designed for overcoming dry and water barriers. These bridges are mounted on the banks, and after mounting their construction are launched over dry or water barrier (Slavkovic et al., 2013). They can be easily adapted to different length or capacity requirements. Their main disadvantage is large mass of the parts of the set, which can significantly slow down the mounting of the bridge itself. These sets are included in the engineering units of the Serbian Army. The bridges made of this material can be found throughout Serbia, and in some places they represent significant link between the two banks.

The selection of location for mounting a single-span Bailey bridge is ideal field for the application of multi-criteria decision making methods. Potential locations where such bridges could be placed usually have significant differences that more or less

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affect the speed of assembly and human and material resources necessary during the construction process (Gordic et al., 2013). By correct selection of location for such bridge can be prevented potential problems in the process of its construction and later use.

In this paper, the selection of location for the construction of a single-span Bailey bridge is carried out using the FUCOM - fuzzy MABAC method. Weight coefficients of criteria are calculated using the FUCOM method, while for ranking alternatives is used fuzzy MABAC method.

Both methods are very young and have not been largely applied so far. The FUCOM method was developed in 2018 by Pamučar et al. (2018). In the same year Prentkovskis et al. (2018) used this method as a part of the model for Improving Service Quality Measurement. Crisp MABAC method was announced for the first time in 2015 by Pamučar and Ćirović (2015). As a new method, it has been noted by the researchers quickly, and now there are many papers using this method in problem consideration, independently or as a part of a hybrid model (Božanić et al., 2016a; Peng & Yang, 2016; Chatterjee et al., 2017; Hondro, 2018; Majchrzycka & Poniszewska, 2018; Ji et al., 2018; Peng & Dai, 2018). In some papers, the method is used in fuzzy environment (Roy et al., 2016; Xue et al., 2016; Sun et al., 2017; Hu et al., 2019; Yu et al., 2017), and it has also appeared combined with rough numbers (Sharma et al., 2018; Roy et al. 2017).

2. Methods

Considering that the hybrid FUCOM – fuzzy MABAC model consists of two methods, in the following section of the paper these two methods will be described in detail.

2.1. FUCOM

This method is a new MCDM method proposed in (Pamučar et al., 2018). In the following section, the procedure for obtaining the weight coefficients of criteria by using FUCOM is presented.

Step 1. In the first step, the criteria from the predefined set of the evaluation criteria $C=\{C_1,C_2,...,C_n\}$ are ranked. The ranking is performed according to the significance of the criteria, i.e. starting from the criterion which is expected to have the highest weight coefficient to the criterion of the least significance. Thus, the criteria ranked according to the expected values of the weight coefficients are obtained:

$$C_{j(1)} > C_{j(2)} > ... > C_{j(k)} \quad (1)$$

where *k* represents the rank of the observed criterion. If there is a judgment of the existence of two or more criteria with the same significance, the sign of equality is placed instead of “>” between these criteria in the expression (1)

Step 2. In the second step, a comparison of the ranked criteria is carried out and the *comparative priority* ($\varphi_{k/(k+1)}$, $k=1,2,...,n$, where *k* represents the rank of the criteria) of the evaluation criteria is determined. The comparative priority of the evaluation criteria ($\varphi_{k/(k+1)}$) is an advantage of the criterion of the $C_{j(k)}$ rank compared to the criterion of the $C_{j(k+1)}$ rank. Thus, the vector of the comparative priorities of the evaluation criteria are obtained, as in the expression: (2)

$$\Phi = \left(\varphi_{1/2}, \varphi_{2/3}, \ldots, \varphi_{k/(k+1)}\right) \tag{2}$$

where $\varphi_{k/(k+1)}$ represents the significance (priority) that the criterion of the $C_{j(k)}$ rank has compared to the criterion of the $C_{j(k+1)}$ rank.

The comparative priority of the criteria is defined in one of the two ways defined in the following part:

a) Pursuant to their preferences, decision-makers define the comparative priority $\varphi_{k/(k+1)}$ among the observed criteria.

b) Based on a predefined scale for the comparison of criteria, decision-makers compare the criteria and thus determine the significance of each individual criterion in the expression (1). The comparison is made with respect to the first-ranked (the most significant) criterion. Thus, the significance of the criteria ($\varpi_{C_{j(k)}}$) for all of the criteria ranked in Step 1 is obtained. Since the first-ranked criterion is compared with itself (its significance is $\varpi_{C_{j(1)}} = 1$), a conclusion can be drawn that the *n-1* comparison of the criteria should be performed.

As we can see from the example shown in Step 2b, the FUCOM model allows the pairwise comparison of the criteria by means of using integer, decimal values or the values from the predefined scale for the pairwise comparison of the criteria.

Step 3. In the third step, the final values of the weight coefficients of the evaluation criteria $\left(w_1, w_2, \ldots, w_n\right)^T$ are calculated. The final values of the weight coefficients should satisfy the two conditions: (1) that the ratio of the weight coefficients is equal to the comparative priority among the observed criteria ($\varphi_{k/(k+1)}$) defined in *Step 2*, i.e. that the following condition is met:

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{3}$$

(2) In addition to the condition (3), the final values of the weight coefficients should satisfy the condition of mathematical transitivity, i.e. that $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$. Since $\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ is obtained. Thus, yet another condition that the final values of the weight coefficients of the evaluation criteria need to meet is obtained, namely:

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{4}$$

Full consistency i.e. minimum DFC (χ) is satisfied only if transitivity is fully respected, i.e. when the conditions of $\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)}$ and $\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}$ are met. In that way, the requirement for maximum consistency is fulfilled, i.e. DFC is $\chi = 0$ for the obtained values of the weight coefficients. In order for the conditions to be met, it is necessary that the values of the weight coefficients $\left(w_1, w_2, \ldots, w_n\right)^T$ meet the condition of $\left|\frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)}\right| \le \chi$ and $\left|\frac{w_k}{w_{k+2}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le \chi$, with the minimization of the value χ. In that manner the requirement for maximum consistency is satisfied.

Based on the defined settings, the final model for determining the final values of the weight coefficients of the evaluation criteria can be defined.

$$\begin{aligned}
&\min \chi \\
&\text{s.t.} \\
&\left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)}\right| \le \chi,\ \forall j \\
&\left|\frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le \chi,\ \forall j \\
&\sum_{j=1}^{n} w_j = 1,\ \forall j \\
&w_j \ge 0,\ \forall j
\end{aligned} \tag{5}$$

2. 2. Fuzzy MABAC method

The MABAC method is developed by (Pamučar & Ćirović, 2015). It is developed as the method providing crisp values. In this paper is carried out its fuzzification. The fuzzyfication is performed using triangular fuzzy numbers. A general form of triangular fuzzy number is given in the Figure 1.

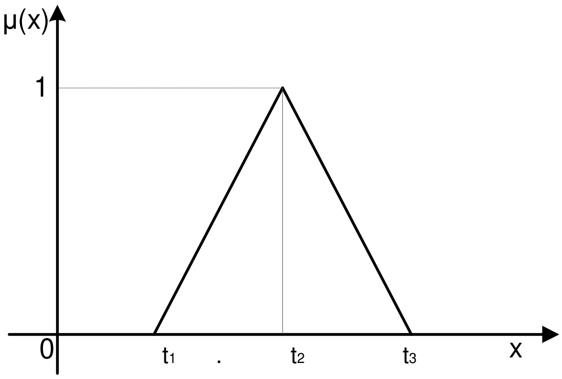

Figure 1. Triangular fuzzy number

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 fuzzyfication of the MABAC method is taken from (Božanić et al., 2018), and its mathematical formulation is presented in seven steps.

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).

$$\tilde{X} = \begin{array}{c} \\ A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \ldots & \tilde{x}_{1n} \\ \tilde{x}_{11} & \tilde{x}_{22} & & \tilde{x}_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ \tilde{x}_{1m} & \tilde{x}_{2m} & \ldots & \tilde{x}_{mn} \end{bmatrix} \end{array} \quad (6)$$

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

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

$$\tilde{N} = \begin{array}{c} \\ A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \ldots & \tilde{t}_{1n} \\ \tilde{t}_{11} & \tilde{t}_{22} & & \tilde{t}_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ \tilde{t}_{1m} & \tilde{t}_{2m} & \ldots & \tilde{t}_{mn} \end{bmatrix} \end{array} \quad (7)$$

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

For benefit-type criteria

$$\tilde{t}_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \quad (8)$$

For cost-type criteria

$$\tilde{t}_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \quad (9)$$

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

$$\tilde{V} = \begin{bmatrix} \tilde{v}_{11} & \tilde{v}_{12} & \ldots & \tilde{v}_{1n} \\ \tilde{v}_{21} & \tilde{v}_{22} & \ldots & \tilde{v}_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ \tilde{v}_{m1} & \tilde{v}_{m2} & \ldots & \tilde{v}_{mn} \end{bmatrix} \quad (10)$$

The elements of the weighted matrix ($\tilde{V}$) are calculated on the basis of the expression (11)

$$\tilde{v}_{ij} = w_i \bullet \tilde{t}_{ij} + w_i \tag{11}$$

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 (12):

$$\tilde{g}_i = \left(\prod_{j=1}^{m} \tilde{v}_{ij} \right)^{1/m} \tag{12}$$

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).

$$\begin{array}{l} \quad\;\; C_1 \quad C_2 \quad \dots \quad C_n \\ \tilde{G} = \left[\tilde{g}_1 \quad \tilde{g}_2 \quad \dots \quad \tilde{g}_n \right] \end{array} \tag{13}$$

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

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

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 ($\tilde{G}$).

$$\tilde{Q} = \tilde{V} - \tilde{G} \tag{15}$$

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 Figure 2.

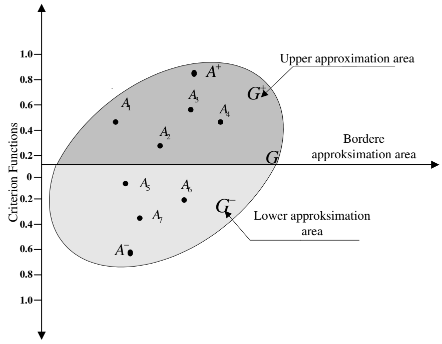

Figure 2. Display of upper ($\tilde{G}^{+}$), lower ($\tilde{G}^{-}$) and border ($\tilde{G}$) approximate area (Pamučar & Ćirović, 2015)

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

$$\tilde{A}_i \in \begin{cases} \tilde{G}^{+} \text{ if } \tilde{q}_{ij} > 0 \\ \tilde{G} \text{ if } \tilde{q}_{ij} = 0 \\ \tilde{G}^{-} \text{ if } \tilde{q}_{ij} < 0 \end{cases} \tag{16}$$

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

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{q}_{ij},\ j = 1,2,\ldots,n,\ i = 1,2,\ldots,m \tag{17}$$

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 next expressions (Seiford, 1996):

$$\text{defazzy } S = \left[(t_3 - t_1) + (t_2 - t_1) \right] 3^{-1} + t_1 \tag{18}$$

$$\text{defazzy } S = \left[\lambda t_3 + t_2 + (1-\lambda) t_1 \right] 2^{-1} \tag{19}$$

3. Description of criteria and calculation of weight coefficients

The criteria for selecting the most favorable location for a single-span Bailey bridge are defined based on the analysis of the available literature. The analysis sets out seven key criteria that have the greatest influence on the selection, and they are the following (Kočić, 2017):

C1- Access roads
C2- Scope of work on site arrangement
C3- Properties of banks
C4- Width of water barrier
C5- Masking conditions
C6- Scope of works on joining access roads with the crossing point
C7- Protection of units

The concept of access roads (C1) refers to the number and quality of the roads by which the resources are brought to the location for construction and launching of the bridge over the water barrier, or close to it. These are the roads with adequate surface which does not require significant repairs and reconstructions. Through this criterion several elements are considered: capacity, number and width of access roads, as well as the position of roads in relation to the barrier (administrative or lateral) (Pamučar et al., 2011).

The scope of work on site arrangement (C2) represents the workload required for the site arrangement. In other words, it refers to the works necessary for arranging a place of work, where the space for storage of the parts of the set is arranged, parking of motor vehicles, place for stuff operation, space for rest, material disposal, and space for assembly and launching of the bridge (Božanić, 2017).

Properties of the banks (C3) refer to the soil composition of the bank, height of the bank, slope of the bank, forestation, artificial barriers, and the like.

The width of water barrier (C4) is defined as the distance from one bank to the other, measured by the surface of water (Pifat, 1980).

Masking conditions (C5) include measures and procedures undertaken to hide the activities and arrangement of the forces, assets and objects from the enemy, in order to lead the enemy to wrong conclusions, to make wrong decisions and apply wrong actions (Rkman, 1984).

Scope of works on joining access roads with the crossing point (C6) refers to the roads that ensure moving the unit from the nearest access road to the crossing point over the water barrier.

Unit protection (C7) is an integral and essential part of every operation. This criterion includes the assessment of the measures that must be taken to ensure required level of unit protection.

The set of criteria from C1 to C7 consists of two subsets:

The "C +" is a set of criteria of the benefit type, which means that the higher value of criteria is more favorable (the criteria C1, C3, C5 and C7), and

the"C -" is a set of criteria of the cost type, which means that the lower value of criteria is more favorable (the criteria C2, C4 and C6).

The criterion C4 is presented as numerical, while the other criteria are presented as linguistic.

The weight coefficients of criteria are obtained by applying the FUCOM method. The evaluation of the weight coefficients is performed by 9 decision makers (DM) – experts in the field of the subject matter. For all decison makers is carried out the evaluation of competence.

In the first step, the decision makers ranked the criteria. After several rounds of harmonization, three groups of ranks of criteria appeared, which are as follows:

- DM1, DM2, DM6, DM7, DM8 and DM9: C1>C2>C3>C4>C5>C6,>C7,
- DM3 and DM5: C1>C2>C5>C4>C3>C6,>C7
- DM4: C2>C1>C3>C4>C5>C6,>C7.

In the second step, the decision makers compared in pairs the ranked criteria from the step 1. The comparison is made according to the first-ranked criterion, based on the scale $\left[1,7\right]$. This is how the importance of the criteria is obtained ($\varpi_{C_{j(k)}}$) for all the criteria ranked in the step 1 (Table 1).

Table 1. Importance of criteria

DM1							
Criteria	C1	C2	C3	C4	C5	C6	C7
Importance ($\varpi_{C_{j(k)}}$)	1	2	2.5	3	3.1	4	5.5
DM2							
Criteria	C1	C2	C3	C4	C5	C6	C7
Importance ($\varpi_{C_{j(k)}}$)	1	2.5	3	3.5	4	5	5
. . .				. . .			
DM9							
Criteria	C1	C2	C3	C4	C5	C6	C7
Importance ($\varpi_{C_{j(k)}}$)	1	2	2.1	3	4	4.5	6

Finally, in the third step and based on the comparison performed by DM, applying the expressions 3-5 are obtained the values presented in the Table 2.

Table 2. Weight coefficient of criteria by every DM individually

DM1							
Criteria	C1	C2	C3	C4	C5	C6	C7
w_j	0.335	0.167	0.134	0.112	0.108	0.084	0.061
DM2							
Criteria	C1	C2	C3	C4	C5	C6	C7
w_j	0.375	0.150	0.125	0.107	0.094	0.075	0.075
. . .				. . .			
DM9							
Criteria	C1	C3	C2	C4	C5	C6	C7
w_j	0.339	0.170	0.162	0.113	0.085	0.075	0.057

Having been obtained the weight coefficients of criteria by every DM, it is performed the calculation of the aggregated weight coefficient. Such calculation was carried out by subsequent synthesis of individual decisions by the method of averaging using geometric mean (*Geometric Mean Method – GMM*) applying the expression (Zoranović & Srđević, 2003):

$$A_i^G = \prod_{k=1}^{K} \left[a_i(k) \right]^{b_k} \tag{20}$$

where:

A_i^G – aggregated value of the weight coefficient,

$a_i(k)$ – value of the weight coefficient for every k-th DM where k=1,...K,

b_k – additionally normalized competence coefficient of the k-th DM;

Final, aggregated values of the weight coefficients are presented in the Table 3.

Table 3. Final weight coefficient of criteria

Criteria	Weight coefficient of criteria
C1	0.311
C2	0.198
C3	0.137
C4	0.112
C5	0.098
C6	0.079
C7	0.065

4. Model testing

The testing of the model, respectively, fuzzy MABAC method is performed with six alternatives. Before the very beginning of the testing, fuzzy linguistic descriptors had been defined which were used to describe linguistic criteria

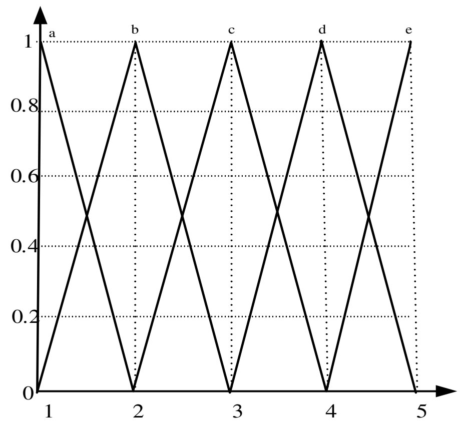

Figure 3. Graphic display of fuzzy linguistic descriptors (Božanić et al., 2016b)

Every criterion can be described with five values:

C1, C3, C5 and C7: a=very bad (VB), b=bad (B), c=medium (M), d=good (G) and e=excellent (E).

C2 and C6: a=very small (VS), b=small (S), c=medium (M), d=large (L), e=very large (VL).

The initial decision making matrix is shown in the Table 4.

Table 4. Initial decision making matrix

	C1	C2	C3	C4	C5	C6	C7
A1	M	L	E	(45,50,56)	M	VS	VB
A2	G	S	M	(39,44,47)	VB	VL	G
A3	VB	VL	G	(47,51,56)	E	S	M
A4	B	M	VB	(46,48,51)	G	VS	VB
A5	M	L	B	(38,42,45)	E	L	G
A6	E	M	G	(45,47,51)	G	S	B

The quantification of linguistic descriptors is shown in the Table 5.

Table 5. Quantification of linguistic descriptors

	C1	C2	C3	C4	C5	C6	C7
A1	(2,3,4)	(3,4,5)	(4,4,5)	(45,50,56)	(2,3,4)	(1,1,2)	(1,1,2)
A2	(3,4,5)	(1,2,3)	(2,3,4)	(39,44,47)	(1,1,2)	(4,4,5)	(3,4,5)
A3	(1,1,2)	(4,4,5)	(3,4,5)	(47,51,56)	(4,4,5)	(1,2,3)	(2,3,4)
A4	(1,2,3)	(2,3,4)	(1,1,2)	(46,48,51)	(3,4,5)	(1,1,2)	(1,1,2)
A5	(2,3,4)	(3,4,5)	(1,2,3)	(38,42,45)	(4,4,5)	(3,4,5)	(3,4,5)
A6	(4,4,5)	(2,3,4)	(3,4,5)	(45,47,51)	(3,4,5)	(1,2,3)	(1,2,3)

Applying steps 1 to 7 of the fuzzy MABAC method, final values for every alternative are obtained, which allow ranking alternatives and selecting the most favorable location for the construction of a Bailey bridge. The Table 6 shows final results by alternatives

Table 6. Ranking of alternatives

	Fuzzy MABAC method		Crisp MABAC method	
	Si	Rank	Si	Rank
A1	0.027	3	0.022	4
A2	0.127	2	0.175	2
A3	-0.110	6	-0.174	6
A4	-0.079	5	-0.077	5
A5	0.021	4	0.073	3
A6	0.168	1	0.219	1

As can be noted in the Table 6, the rank of criteria slightly differs when applying crisp and fuzzified MABAC method. The main difference is in the ranking of alternatives A1 and A5. It is also noted that the obtained values by alternatives are not the same, but that does not have a significant influence to the rank of criteria.

5. Sensitivity analysis

In this section is presented sensitivity analysis, as a logical sequence of the development of the multi-criteria decision-making model.The sensitivity assessment was done by changing the weight coefficients of the criteria, using seven different scenarios, where in each scenario the second criterion was favorable (Pamučar et. al. 2017). The display of weight coefficients according to the scenarios is given in Table 7.

Table 7. Weight coefficient in different scenario

Criteria	S-0	S-1	S-2	S-3	S-4	S-5	S-6	S-7
C1	0.311	0.4	0.1	0.1	0.1	0.1	0.1	0.1
C2	0.198	0.1	0.4	0.1	0.1	0.1	0.1	0.1
C3	0.137	0.1	0.1	0.4	0.1	0.1	0.1	0.1
C4	0.112	0.1	0.1	0.1	0.4	0.1	0.1	0.1
C5	0.098	0.1	0.1	0.1	0.1	0.4	0.1	0.1
C6	0.079	0.1	0.1	0.1	0.1	0.1	0.4	0.1
C7	0.065	0.1	0.1	0.1	0.1	0.1	0.1	0.4

The values obtained by applying different scenarios are given in Table 8.

Table 8. Ranking of alternatives by applying different scenarios

Alter. index	S-1		S-2		S-3		S-4		S-5		S-6		S-7	
	S_i	Rank	S_i	Rank	S_i	Rank	S_i	Rank	S_i	Rank	S_i	Rank	S_i	Rank
A1	0.024	4	-0.020	5	0.149	1	-0.034	4	-0.021	5	0.131	1	-0.071	5
A2	0.113	2	0.143	1	0.038	4	0.097	2	-0.132	6	-0.105	6	0.143	2
A3	-0.114	6	-0.084	6	0.086	2	-0.064	6	0.091	3	0.067	3	0.040	3
A4	-0.098	5	0.007	3	-0.148	6	-0.048	5	0.007	4	0.084	2	-0.118	6
A5	0.048	3	0.003	4	-0.027	5	0.134	1	0.128	1	-0.046	5	0.152	1
A6	0.189	1	0.094	2	0.064	3	0.051	3	0.094	2	0.046	4	0.019	4

Based on sensitivity analysis of the results from the Table 8, it can be observed that the model in the midst of change of weight coefficients provides also the change of ranks of the given alternatives. It is interesting to note, though, that the first-ranked alternative A6, no matter the scenario, not once was ranked as the fifth or the sixth, and the alternative A3 which was ranked as the last, not in one scenario appeared as the first one.

For the mathematical determination of the correlation of ranks, the values of Spirman's coefficient were used:

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

where is:

- S - the value of the Spirman coefficient,
- Di - the difference in the rank of the given element in the vector w and the rank of the correspondent element in the reference vector,

– n - number of ranked elements.

The rank of each criterion - the alternative is determined based on the weight coefficient vector $w=(w_1, w_2, ..., w_n)$.

Spirman's coefficient takes values from the interval [-1,1]. When the ranks of the elements completely coincide, the Spirman coefficient is 1 ("ideal positive correlation"). When the ranks are completely opposite, the Spirman coefficient is -1 ("ideal negative correlation"), that is, when S = 0 the ranks are unregulated.

Table 9. Spirman's coefficient values

	S-0	S-1	S-2	S-3	S-4	S-5	S-6	S-7
S-0	1	0.964	0.821	0.464	0.750	0.286	0.143	0.429
S-1		1	0.857	0.321	0.857	0.429	0.000	0.571
S-2			1	0.071	0.714	0.214	0.000	0.429
S-3				1	0.214	0.250	0.607	0.607
S-4					1	0.500	-0.071	0.786
S-5						1	0.286	0.696
S-6							1	-0.143
S-7								1

As observed from the table of Spearman's coefficient values, it ranges from -0.143 to 0.964. The differences in the ranks of alternatives point out the sensitivity of the model to changes of weight coefficients. On the other hand, low Spearman's coefficient in certain scenarios indicates the necessity of careful evaluation of alternatives by criteria, because potential errors could reflect on the final rank of alternatives. What is important is that the values of Spearman's coefficient, in relation to the S-0 strategy (according to calculated weight coefficients) are fairly high compared to all the other strategies.

6. Conclusions

The introduction of the model into the decision-making processes has proved to be very useful. In the specific case, deciding based on the application of the model has created the conditions for persons with less experience to make a decision. Also, this kind of decision making helps decision makers to perceive complete picture of the impact of all the conditions in which a Bailey bridge is constructed. On the other hand, deciding without applying the model creates the possibility of ignoring or neglecting a part of criteria during decision making.

The application of the fuzzified MABAC method is shown throughout the paper. It can be observed that the outputs in the application of crisp and fuzzified MABAC methods are not identical, which leaves space for further research. Certainly, fuzzified MABAC method provides greater scope for considering uncertainty, which is common in linguistic descriptors.

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