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THE SELECTION OF A LOCATION FOR POTENTIAL ROUNDABOUT CONSTRUCTION – A CASE STUDY OF DOBOJ

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Abstract: *The increase in the number of traffic accidents, as well as the development of modern traffic signaling, have influenced realistic traffic solutions at intersections to be aimed at constructing roundabouts, which has increased the capacity and safety of traffic participants. This paper has several goals that refer to the development of methodology for evaluating potential locations for roundabout construction. The subject of this research is based on the development of a model for the construction of a roundabout in Doboj using the integrated BWM (Best Worst Method) and MABAC (Multi-Attributive Border Approximation area Comparison) approach. Taking into account the fact that Doboj is a transport hub where many roads intersect and that it is a very important transit point, the necessity of constructing roundabouts is justified. Therefore, as part of the paper, an adequate methodology has been developed for an optimal selection of a potential location for the construction of a roundabout.*

Key words: *roundabout, location, sustainable traffic, BWM, MABAC,*

1. Introduction

In European countries, experts believe that roundabouts reduce the number of accidents and cause capacity increase, making their usage attractive since the 1980s. In the Netherlands, France, Norway, Denmark and other European countries, the number of roundabouts has been increasing progressively. In the Netherlands (Vasilyeva and Sazonova, 2017), turbo-roundabouts are being introduced with 20 to 30% higher speeds of movement in them and with greater safety. At intersections regulated by light signals, the problem occurs since pedestrian and vehicle flows intersect, which adversely affects pedestrians as a "vulnerable" category. This case is especially dominant at Russian signalized intersections, where drivers often drive under the influence of alcohol or pass the crossroad on red light. (Vasilyeva and

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Sazonova, 2017) According to the research (Møller and Hels, 2007), the performance of roundabouts was considered by the criteria of road properties, capacity and location. Their research consists of observing two types of roundabouts, with and without pedestrian crossings and cycle paths.

The trend of constructing roundabouts has also shifted to smaller urban areas, so when looking at the territory of the Republic of Srpska it is possible to see a constant increase of roundabouts in urban areas. Urban areas Bijeljina, Derventa, Trebinje, Prnjavor and others are an example of that. To solve traffic congestion and increase safety on main roads, roundabouts are being constructed extensively. When it comes to the territory of the city of Doboj and the main roads passing through the city, the number of roundabouts is zero. Taking into account the fact that Doboj is a transport hub where many roads intersect and that it is a very important transit point, the necessity of constructing roundabouts is justified.

The subject of this paper is to define potential locations for the construction of roundabouts in the area of the City of Doboj. The main objective of the paper is to identify priority intersections on the entire street network of the City of Doboj. A roundabout falls into the category of at-grade intersections, where all entering streams flow in and exiting streams flow out of usually one-way traffic flow around the central island of the intersection. Based on this, it has been formed a hypothetical assumption which implies that the introduction of a roundabout on the current street network is functionally dependent on traffic conditions and their effects on the current traffic infrastructure in the urban area of the City of Doboj. In addition, the location of a roundabout in Doboj depends on the potential urban-planning and technical conditions for the implementation of the intersection, and any potential solution can influence the change in modernity of the traffic infrastructure.

After the introduction, the second section presents an overview of the situation in the field of interest with a brief review of multi-criteria decision-making methods. The third section provides the algorithms of the methods used in this paper: MABAC, BEST WORST. The fourth section is a case study of selecting a location for the construction of a roundabout in the City of Doboj using the BWM-MABAC model. The paper ends with conclusions presenting contributions of the paper and directions for future research.

2. Brief literature review

Increasing capacity in road engineering according to (Li et al., 2014) has become an important way of solving traffic problems, and roundabouts, in addition to a large number of benefits, also cause the increase in traffic capacity (Prateli, 2006), and higher traffic flow rate (Retting et al. 2006). A properly constructed roundabout, according to (Prateli et al., 2018), can have a significant impact on increasing traffic safety, which is also confirmed by (Antov et al., 2009), who find that the construction of roundabouts is an efficient measure to increase safety.

Depending on the type of location problem, different methods are used as shown above. In the last decade, multi-criteria decision-making (MCDM) methods have been applied widely in addressing location problems (Chauhan and Singh, 2016; Nie et al., 2017; Samanlioglu and Ayag, 2017; Zhao et al., 2018; Nazari et al., 2018). Zhao et al. (2018) use a combination of AHP and TOPSIS methods to develop a metro-integrated logistics system. Using the TOPSIS method, they performed a significance evaluation for each metro station. Nazari et al. (2018) conducted a study to select a suitable site for photovoltaic installation in Iran.

3. Methods

Psychology provides an explanation why individuals frequently make irrational decisions, while economics proposes normative theories (Morselli, 2015). According to (Triantaphyllou and Mann, 1995), multi-criteria decision-making plays an important role in real-life problems since there are many everyday decisions to be made that involve a large number of criteria, whereas, according to (Chen et al., 2015), multi-criteria decision-making is an efficient, systematic and quantitative method of solving vital real-life problems in the presence of a large number of alternatives and several (opposing) criteria.

The BEST WORST (Rezai, 2015) method was used to determine the weight values of criteria, while the MABAC method was used to evaluate the intersection locations for the construction of a roundabout.

In addition, to determine model validity through a sensitivity analysis, four other multi-criteria decision-making methods were used: ARAS (Zavadskas and Turksis, 2010) WASPAS (Zavadskas and Turksis, 2012), SAW (Macrimon, 1968), and EDAS (Ghoarabaee et al., 2016).

3.1. Best – Worst Method

The following section presents the algorithm of the BW method based on interval rough numbers. Determining the weight coefficients of evaluation criteria using the IRN-BW method includes the following steps:

Step 1. Determining a set of evaluation criteria. In this step, we consider a set of evaluation criteria C = {C_1, C_2, ... C_n}, where *n* represents the total number of criteria.

Step 2. Determining the most significant (most influential) and worst (least influential) criterion. If there are two or more criteria that are best, i.e. worst, it is arbitrary to choose the best, i.e. the worst criterion.

Step 3. Determining the preferences of the most significant (most influential) criterion in a set C over all other criteria in a defined set. The scale of numbers in the interval of 1-9 is used to determine the preferences. As a result, the best-to-others (BO) vector is obtained:

$$A_B = (a_{B1}, a_{B2,.....,} a_{Bn}) \tag{1}$$

where a_{Bj} represents the influence (preference) of the best criterion B over the criterion *j*, while $a_{BB} = 1$.

Step 4. Determining the preferences of all criteria in a set C over the worst (least influential) criterion in a defined set. To determine the preferences, as in *Step 3*, a scale of numbers in the interval of 1-9 is used. The result is obtaining the others-to-worst (OW) vector:

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW}) \tag{2}$$

where a_{Bj} represents the influence (preference) of the criterion *j* over the worst criterion *W*, while $a_{BB} = 1$.

Step 5. Calculation of optimal values of the weight coefficients of the criteria in a set C, $(w_1^*, w_2^*, \dots, w_n^*)$. The aim is to determine the optimal values of the evaluation criteria, which should satisfy the condition that the maximum absolute gaps (3)

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \quad and \quad \left|\frac{w_j}{w_W} - a_{jW}\right| \tag{3}$$

for all values of *j* be minimized. In order to satisfy these conditions, a solution that satisfies the maximum gaps by absolute value $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_w} - a_{jW}\right|$ should be minimized for all values of *j*. This condition can be shown through the following min-max model:

$$\min \max_j \left\{ \left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{w_W} - a_{jW}\right| \right\}$$
$$s.t.$$
$$\sum_{j=1}^{n} w_j = 1$$
$$w_j \geq 0 \quad \forall j \tag{4}$$

The presented model (4) is equivalent to the following model:

$$\min \xi$$
$$s.t.$$
$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi, \forall j$$
$$\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi, \forall j$$
$$\sum_{j=1}^{n} w_j = 1$$
$$w_j \geq 0 \quad \forall j \tag{5}$$

By solving the system of equations and inequations of model (5), we obtain the optimal values of the weight coefficients of the evaluation criteria $(w_1^*, w_2^*, \dots, w_n^*)$ and ξ^*.

Definition 1. The criterion comparison is consistent when the condition that $a_{Bj} \times a_{jW} = a_{BW}$ is fulfilled for all criteria *j*, where a_{Bj} , a_{jW} and a_{BW} respectively represent the influence (preference) of the best criterion over the criterion *j*, the influence (preference) of the criterion *j* over the worst criterion, and preference of the best criterion over the worst criterion.

However, when comparing criteria, it may be that for some pairs of criteria *j*, the comparisons are not fully consistent. Therefore, the following section defines a consistency ratio (CR) that provides information on the consistency of the BO and OW comparisons. To show the determination of CR, we start from the calculation of the minimum consistency in the comparison of criteria, which is explained in the following section.

As noted above, pair-wise comparisons of criteria are made on the basis of the scale $a_{ij} \in \{1,2,\dots,a_{BW}\}$, where the highest value from scale a_{BW} is a value of 9 or any other maximum value of a scale defined by the decision-maker. The consistency of the comparison decreases when $a_{Bj} \times a_{jW}$ is lower or higher than a_{BW}, i.e. when $a_{Bj} \times a_{jW} \neq a_{BW}$.

It is clear that the greatest inequality occurs when a_{Bj} and a_{jW} have maximum values that are equal to a_{BW}, which further affects the values of ξ. Based on the relations defined above, we can conclude that there is a relation as follows:

$$\left(w_B/w_j\right) \times \left(w_j/w_W\right) = w_B/w_W \tag{6}$$

Since the greatest inequality occurs when a_{Bj} and a_{jW} have maximum values (a_{BW}), then the value of ξ needs to be subtracted from a_{Bj} and a_{jW} and added to a_{BW}.

Thus, we obtain Expression *(7):*

$$\left(a_{Bj} - \xi\right) \times \left(a_{jW} - \xi\right) = \left(a_{BW} + \xi\right) \tag{7}$$

Since the minimum consistency implies the equality that $a_{Bj} = a_{jW} = a_{BW,}$ Expression (7) is presented as follows:

$$\left(a_{BW} - \xi\right) \times \left(a_{BW} - \xi\right) = \left(a_{BW} + \xi\right) \Rightarrow \xi^2 - \left(1 - 2a_{BW}\right)\xi + \left(a_{BW}{}^2 - a_{BW}\right) = 0 \tag{8}$$

For different values of $a_{BW} \in \{1,2,\dots,9\}$ based on Expression (8), we obtain maximum values of ξ (max ξ). Table 1 presents the maximum values of ξ (consistency index) for different values of $a_{BW} \in \{1,2,\dots,9\}$.

Table 1. Consistency Index (CI) values

a_{BW}	1	2	3	4	5	6	7	8	9
CI ($\max \xi$)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Based on CI (Table 2), we obtain a consistency ratio (CR)

$$CR = \frac{\xi^*}{CI} \tag{9}$$

CR takes values from the interval $\left[0,1\right]$, where values closer to zero show high consistency, while *CR* values closer to one show low consistency.

The solution space of model (5) includes all positive values of w_j ($j = 1,2,\dots n$) that satisfy two conditions: (1) the sum of all weight coefficients should be equal to one and (2) the ratio of the weighted coefficients of the criteria which are compared should be at most equal to ξ.

3.2. MABAC method

The MABAC (Multi-Attributive Border Approximation area Comparison) method is a recent method. The MABAC method was developed by Dragan Pamučar at the Center for Defense Logistics Research at the University of Defense in Belgrade and was first introduced to the scientific community in 2015 (Pamučar and Ćirović, 2015). So far, it has found wide application and modification in solving various problems in the field of multi-criteria decision-making.

The basis of the MABAC method is seen in the definition of the distance of the criterion function of each alternative from the border approximation area. The following section shows the process of implementing the MABAC method, consisting of six steps:

Step 1. Formation of the initial decision matrix (X).

$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \end{array} \tag{10}$$

Step 2. Normalization of the elements from the initial matrix (X).

$$N = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} t_{11} & t_{12} & \dots & t_{1n} \\ t_{21} & t_{22} & & t_{2n} \\ \dots & \dots & \dots & \dots \\ t_{m1} & t_{m2} & \dots & t_{mn} \end{bmatrix} \end{array} \tag{11}$$

The elements of the normalized matrix (N) are determined by applying the following expressions:

For benefit-type criteria (higher criterion value is preferable)

$$t_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{12}$$

For cost-type criteria (lower criterion value is preferable)

$$t_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{13}$$

where

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

$x_i^+ = \max(x_1, x_2, \dots, x_m)$ and represents the maximum values of the observed criterion by alternatives.

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

$$v_{ij} = w_i \cdot t_{ij} + w_i \tag{14}$$

where t_{ij} represents the elements of the normalized matrix (N), w_i represents the weight coefficients of criteria. By applying Expression (14), we obtain the weighted matrix V.

$$V = \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1n} \\ v_{21} & v_{22} & & v_{2n} \\ \dots & \dots & \dots & \dots \\ v_{m1} & v_{m2} & \dots & v_{mn} \end{bmatrix} = \begin{bmatrix} w_1 \cdot t_{11} + w_1 & w_2 \cdot t_{12} + w_2 & \dots & w_n \cdot t_{1n} + w_n \\ w_1 \cdot t_{21} + w_1 & w_2 \cdot t_{22} + w_2 & \dots & w_n \cdot t_{2n} + w_n \\ \dots & \dots & \dots & \dots \\ w_1 \cdot t_{m1} + w_1 & w_2 \cdot t_{m2} + w_2 & \dots & w_n \cdot t_{mn} + w_n \end{bmatrix}$$

where n represents the total number of criteria, m represents the total number of alternatives.

Step 4. Determining the border approximation area matrix (G).

$$g_i = \left(\prod_{j=1}^{m} v_{ij} \right)^{1/m} \tag{15}$$

where v_{ij} represents the elements of the weighted matrix (V), m represents the total number of alternatives.

After calculating the values of g_i by criteria, a border approximation area matrix G (16) of the form $n \, x \, 1$ is created (n represents the total number of criteria by which the offered alternatives are selected).

$$\begin{array}{c} \quad\; C_1 \quad C_2 \quad \dots \quad C_n \\ G = \begin{bmatrix} g_1 & g_2 & \dots & g_n \end{bmatrix} \end{array} \tag{16}$$

Step 5. Calculation of matrix elements of alternative distance from the border approximation area (Q).

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

The distance of alternatives from the border approximation area (q_{ij}) is determined as the difference of the weighted matrix elements (V) and the values of the border approximation areas (G)

$$Q = V - G = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} - \begin{bmatrix} g_1 & g_2 & \cdots & g_n \end{bmatrix} \tag{18}$$

$$Q = \begin{bmatrix} v_{11} - g_1 & v_{12} - g_2 & \cdots & v_{1n} - g_n \\ v_{21} - g_1 & v_{22} - g_2 & \cdots & v_{2n} - g_n \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} - g_1 & v_{m2} - g_2 & \cdots & v_{mn} - g_n \end{bmatrix} = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{19}$$

where g_i represents the border approximation area for the criterion C_i, v_{ij} represents the elements of the weighted matrix (V), n represents the number of criteria, m represents the number of alternatives.

The alternative A_i can belong to the border approximation area (G), the upper approximation area (G^+) or the lower approximation area (G^-), i.e. $A_i \in \{G \vee G^+ \vee G^-\}$

The upper approximation area (G^+) represents the area where the ideal alternative (A^+) is located, while the lower approximation area (G^-) represents the area where the anti-ideal alternative (A^-) is located. The affiliation of the alternative A_i to the approximation area (G, G^+ or G^-) is determined on the basis of Expression (20)

$$A_i \in \begin{cases} G^+ \ if \ q_{ij} > g_i \\ G \ \ if \ q_{ij} = g_i \\ G^- \ if \ q_{ij} < g_i \end{cases} \tag{20}$$

In order for the alternative A_i to be selected as the best alternative of the set, it should belong to the upper approximation area (G+) by as many criteria as possible. For instance, if the alternative belongs to the upper approximation area by five criteria (out of a total of six criteria), and to the lower approximation area (G^-) by one criterion, it means that the alternative is close or equal to the ideal alternative by five criteria, while it is close or equal to the anti-ideal alternative by one criterion. If the value of $q_{ij} > 0$, i.e. $q_{ij} \in G^+$, then the alternative A_i is close or equal to the ideal alternative. The value of $q_{ij} < 0$, i.e. $q_{ij} \in G^-$, indicates that the alternative A_i is close or equal to the anti-ideal alternative.

Step 6. Ranking alternatives. The calculation of the values of criterion functions by alternatives (21) is obtained as the sum of the distances of alternatives from the border approximation area (q_i). By summing the elements of the matrix Q by rows, we obtain the final values of the criterion functions of alternatives

$$S_i = \sum_{j=1}^{n} q_{ij}, \ j = 1,2,...,n, \ i = 1,2,...,m \tag{21}$$

where n represents the number of criteria, m represents the number of alternatives.

4. A case study in the city of Doboj – Description of the situation in the City of Doboj

The selection of the location for the construction of a roundabout consists of several stages that are described in detail below. The first stage implies the formation of a multi-criteria model based on the realistic needs for traffic infrastructure in the city of Doboj. The second stage implies the collection of data on the basis of measurements of traffic indicators and other sources, such as the Ministry of Interior, where data on the number of traffic accidents at the locations for roundabout construction were obtained. The third stage refers to the expert evaluation of the significance of criteria as the first step and the determination of the weights of the criteria using the BWM method as the second step. The fourth stage is the evaluation of the locations based on the MABAC method. This paper will analyze six potential locations for the introduction of a roundabout intersection in the city of Doboj, where no roundabout has been constructed so far. As already mentioned, the city of Doboj, by its geographical position, is located at the crossroads of the most important main and regional roads in the Republic of Srpska and Bosnia and Herzegovina.

This research involved traffic experts. They are on average 50 years old and there were 62 respondents.

The 105 main road (M1) passes in the north-south direction and, in the east, it is connected to the 110 main road from (M1) the direction of Tuzla (Federation of BiH). The most frequent part of the 105 main road (M1) is on the Šešlije - Doboj - Karuše - Federation of BiH route.

The intersections of city streets with access to the main roads are not well resolved in the city, which significantly hinders a normal flow of traffic, especially at peak hours. Taking into account the transport significance of the city of Doboj, as well as the fact that nearby towns, such as Modriča, Derventa, Teslić and many other smaller towns and municipalities already have roundabouts, six potential intersections have been selected for the construction of a roundabout in the city, as well as on the 105 main road (M1). The following table gives an overview of the potential coordinates for the roundabout.

Table 2. Coordinates for the roundabout

Location	A1	A2	A3	A4	A5	A6
Coordinates	44.743443 18.095140	44.735776 18.096611	44.733405 18.096111	44.726579 18.091869	44.713155 18.080535	44.730244 18.081451

4.1. Forming a multi-criteria model

Six locations, out of which one is located in the very center of the city, four locations representing the connection between the streets for the entrance into/exit from the city and the first-order main road, and one location where the first-order main roads intersect, are evaluated on the basis of a total of eight criteria presented in Table 3.

Table 3. Criteria in a multi-criteria model and their description

No.	Criterion	Criterion description
1	Flow of vehicles	The number of vehicles passing through the observed road intersection in a unit of time in both directions
2	Flow of pedestrians	The number of pedestrians crossing the observed intersection at the point for pedestrian movement (pedestrian crossing, zebra, etc.) at a given time interval
3	Traffic Safety Indicator	The number of traffic accidents on the observed section of road
4	Cost of construction and exploitation	Cost estimation (construction, exploitation and maintenance)
5	Type of intersection	Three-way or four-way intersections
6	Average vehicle intensity per access arm	The limit intensity is the intensity at the entry arm into the intersection of 360 PA/h
7	Functional criterion of spatial fitting	What is the primary role of the intersection observed? This section analyzes what type of intersection is the most acceptable due to its role in traffic
8	Public opinion	It implies a survey of local people who have chosen one of the offered locations as a priority for the construction of a roundabout.

The criteria were selected according to the current needs of the City of Doboj and relevant literature that considered similar studies (Day et al., 2013; Benekohal and Atluri, 2009; Deluka-Tibljaš et al., 2010; Steiner et al., 2014). In all the aforementioned studies, the criteria are organized into several categories: traffic criteria, safety criteria, functional criteria, performance, cost, etc. The criteria used in this study are the most commonly used criteria in Croatia: functional criterion, spatially-urbanistic criterion, traffic flow criterion, design and technical criterion, traffic safety criterion, capacity criterion, environmental criterion, economic criterion; in Serbia and Slovenia: functional criterion, capacity criterion, spatial criterion, design and technical criterion, traffic safety criterion and economic criterion (Kozić et al., 2016). The results provided by the study (Retting et al., 2007) indicate that public support increases with time since traffic participants become more familiar and comfortable with this form of traffic control. Considering this, the use of the last criterion in this research has its justification.

4.2. Evaluating and ranking the locations for roundabout construction using the MABAC method

Flow measurement was performed at the sampling level in the period September-November 2017. The data collected for each location based on established criteria are presented in Table 4.

Table 4. Values of alternatives according to criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
A_1	1256	8	2	3	3	419	7	85
A_2	2194	4	2	9	3	731	5	89
A_3	1037	5	4	7	3	346	3	45
A_4	2878	32	3	7	4	720	5	8
A_5	1052	2	4	5	4	263	5	27
A_6	4197	124	1	3	4	1050	7	74

Table 4 shows the values for all the locations by established criteria. It can be noticed that the highest intensity of traffic flows of vehicles and pedestrians belongs to the sixth location with 4197 vehicles and 124 pedestrians in one hour. Locations 4 and 2 have slightly less intensity regarding vehicle flows, while the intensity of pedestrians is 32 for the fourth, and only four for the second location. The remaining locations have double less intensity than the two previously mentioned locations, and almost four times less than the sixth location. If the sixth and fourth locations are excluded, the flows of pedestrians are very low. The reason is that the sixth location is in the city center, and the fourth location represents the connection between entering the city and the railway station. Regarding the number of traffic accidents, the largest number of accidents occurred at locations 3 and 5, four accidents per each, while the lowest number of accidents occurred at the sixth location. The average vehicle intensity per an arm (Table 4) is the largest at the sixth location, 1050, while for the second and fourth location it is almost identical, 731 and 720, respectively. The minimum intensity per an arm is at the fifth location since this location has four arms and an additional arm that is not presented in the paper as an arm, as it is a side road with no frequent traffic. Based on the public opinion survey for potential locations, the largest number of citizens have characterized the first two locations as a priority for the construction of a roundabout, and as the third one, they designated the sixth location.

After obtaining the matrix Q, it is necessary to sum the elements by rows and rank them. Table 5 shows the final values of roundabout locations using the MABAC method.

Table 5. Final values and ranking the alternatives

	Values	**Rank**
A_1	-0.042	**5**
A_2	0.010	**4**
A_3	-0.043	**6**
A_4	0.074	**3**
A_5	0.132	**2**
A_6	0.167	**1**

5. Sensitivity analysis

In order to validate the model and test the results obtained by applying the MABAC method, a sensitivity analysis consisting of the application of the ARAS (Table 6), EDAS (Table 7), SAW (Table 8), and WASPAS (Table 9) methods is performed in the paper.

5.1. Ranking the locations using the ARAS method

Compared to MABAC and other methods used in this paper, the initial matrix for the ARAS method is slightly different. It is reflected through the formation of an additional row that represents the optimal alternative. This alternative consists of the best values depending on the type of criteria. If it is a criterion belonging to the benefit group, the maximum value is taken, while for the criteria belonging to the cost group, the minimum value is taken. After forming the optimal alternative, the initial matrix is as shown in Table 6.

Table 6. Ranking the locations using the ARAS method

	Si	Ki	Rank
A1	0.111	0.519	6
A2	0.134	0.626	3
A3	0.122	0.573	5
A4	0.131	0.614	4
A5	0.144	0.673	2
A6	0.144	0.675	1
Ao	0.214	1.000	

5.2. Ranking the locations using the EDAS method

Table 7. Results obtained using the EDAS method

	SPI	NSI	NSPI	NSNI	ASI	Rank
A_1	0.080	0.177	0.233	0.462	0.348	6
A_2	0.167	0.118	0.488	0,.642	0.565	1
A_3	0.189	0.210	0.554	0.363	0.459	5
A_4	0.149	0.144	0.435	0.563	0.499	4
A_5	0.253	0.201	0.740	0.390	0.565	2
A_6	0.342	0.329	1.000	0.000	0.500	3

5.3. Ranking the locations using the SAW method

Table 8. Ranking the locations using the SAW method

	Values	Rank
A_1	0.547	6
A_2	0.634	3
A_3	0.595	5
A_4	0.633	4
A_5	0.694	2
A_6	0.694	1

5.4. Ranking the locations using the WASPAS method

This method, as already mentioned in the paper, contains the previously applied SAW method in its steps, so that the normalization, weighting of the normalized matrix, and summarizing the values by alternatives are identical as by the SAW method, thus there is no need to display those matrices.

Table 9. Ranking the locations using the WASPAS method

	WPM	Qi	Rank
A_1	0.508	0.528	6
A_2	0.615	0.624	2
A_3	0.522	0.558	5
A_4	0.564	0.599	4
A_5	0.576	0.635	1
A_6	0.514	0.604	3

Based on the presented calculation, it can be noticed that the location under the number 6 is best and a priority for the construction of a roundabout. Since it is the location that has the largest traffic flow of pedestrians, an alternative solution for this location is the installation of traffic lights at this intersection, which has been done in the meantime, as it is well-known that if there is a high rate of pedestrians at a roundabout, alternative solutions are used. The intensity of pedestrians at this location for the period of one hour is 124 and, according to the authors' opinion, it is not a limitation for the roundabout construction. Location 6 represents the location in the city center. The second priority location for the construction of a roundabout is location 5 representing the last exit from the city towards Sarajevo and which is a four-way intersection with an additional side road. There is often traffic congestion at this intersection where city streets are its arms, so there is often a situation where drivers carelessly merge onto the main road, as evidenced by a number of accidents. Considering the above, the priority for the construction of a roundabout at this location is justified.

Since there is a change in the ranks of the alternatives, it is necessary to make a statistical comparison of the ranks, i.e. to determine their correlation. Table 10 shows Spearman's correlation coefficient of the ranks of the alternatives for all the methods used.

Table 10. Spearman's correlation coefficient of the ranks of the alternatives for all the methods used

Methods	MABAC	ARAS	WASPAS	SAW	EDAS	Average
MABAC	1.000	0.886	0.657	0886	0.543	0.794
ARAS	-	1.000	0.829	1.000	0.771	0.900
WASPAS	-	-	1.000	0.829	0.943	0.924
SAW	-	-	-	1.000	0.771	0.886
EDAS	-	-	-	-	1.000	1.000
Overall average						0.901

Based on the total calculated statistical correlation coefficient (0.910), it can be concluded that the ranks are in a high correlation in all the created scenarios. Regarding the rank correlation of MABAC with other methods, there is a high correlation with ARAS and SAW methods, while there is a lower correlation with the other two methods, with WASPAS 0.657 and with EDAS 0.543. ARAS has the total correlation with the SAW method (1.000), with WASPAS (0.829), while it has the lowest correlation of 0.771 with EDAS. WASPAS and EDAS have the highest correlation between each other, when considering these two methods, and it is 0.943. By observing the overall ranks and correlation coefficients, it can be concluded that the model obtained is very stable and the ranks are in a high correlation since all values higher than 0.80 according to (Keshavarz Ghorabaee et al., 2016) represent a very high correlation of ranks.

6. Conclusion

The developed model that includes the integration of BWM and MABAC methods has been applied in a case study of selecting the location for the construction of a roundabout in the City of Doboj, which is one of the important factors for increasing the mobility and functional sustainability of the city. Taking into account the geographical position of Doboj, it is imperative to construct roundabouts on the territory covered by this urban area. Its location affects a significant share of transit flows, increasing negative externalities to traffic sustainability. The solution is certainly the construction of roundabouts that significantly eliminate or reduce current negative effects. The hypotheses set out in the paper have been proven through the development of the integrated model and analysis of all necessary parameters, which can be seen from the results obtained. The paper considers six potential locations, which have been evaluated using the integrated multi-criteria model.

Based on the obtained results, it can be concluded that the sixth location is best in terms of the defined optimization criterion and represents a priority location for the construction of a roundabout. Location 6 represents the location that is in the city center. The second priority location for the construction of a roundabout is location 5 representing the last exit from the city towards Sarajevo and a four-way intersection with an additional side road. There is frequently traffic congestion at this intersection where city streets are its arms. Taking into account the above, the priority for the construction of a roundabout at the mentioned locations has been evaluated as justified. The model stability was verified throughout a sensitivity analysis in which the scenarios were created by applying different approaches.

When observing the current state in the field of interest and infrastructure construction that involves smaller local projects, it is often one or two criteria considered when building infrastructure. The development of such a model as in this research creates the possibility of comprehensive consideration of all the important factors for infrastructure construction, which is one of the contributions of this research. In addition to the traffic flows of vehicles that are the main criterion, it is necessary to take into account the number of traffic accidents that occurred at the considered locations, pedestrian traffic flows, the economic aspect of construction and other factors covered in detail throughout the paper.

Future research with respect to this paper refers to the development of a model that will enable the measurement of parameters that enhance traffic sustainability and the possibility of developing new approaches in the area of multi-criteria decision-making.

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