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EVALUATION OF TWO-LANE ROAD SECTIONS IN TERMS OF TRAFFIC RISK USING AN INTEGRATED MCDM MODEL

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Abstract. The impact of geometric characteristics on traffic risk is reflected through identifying conflict points on roads, traffic accidents, and any other unforeseen situation that is inherently hazardous for traffic participants. In order to identify the road sections with the highest risk, it is necessary to consider a number of criteria that affect risk, and conduct extensive empirical research, analysis and data synthesis. This paper evaluates 9 sections of two-lane roads in the territory of Bosnia and Herzegovina (the Republic of Srpska) using an integrated Multi-Criteria Decision-Making (MCDM) model. To determine the significance of 8 criteria for the evaluation of the sections, it was applied a subjective–objective model consisting of 3 methods: (1) CRiteria Importance Through Inter-criteria Correlation (CRITIC), (2) FUll COnsistency Method (FUCOM) and (3) fuzzy PIvot Pairwise RElative Criteria Importance Assessment (PIPRECIA). The aggregation of the criterion values obtained using the methods yielded the final criterion values. Measurement Alternatives and Ranking according to COmpromise Solution (MARCOS) method was used to evaluate the sections and determine their objective diversity. The obtained results identified one location as extremely hazardous by most of analysed input parameters. The section with the highest risk is the Rudanka – Doboj section (A4), which represents a section of the road infrastructure of the 105 road. The validation of the results obtained by applying the integrated MCDM model was performed through an extensive sensitivity analysis. The weights of criteria were observed through initially individual methods implemented in the MARCOS method. Then, a comparative analysis was performed with 6 other MCDM methods and Spearman's Correlation Coefficient (SCC) was calculated as a statistical indicator of rank correlation in a sensitivity analysis. In addition, the Standard Deviation (STDEV) of the obtained results was determined.

Keywords: traffic risk, road sections, MARCOS, FUCOM, CRITIC, fuzzy PIPRECIA.

Notations

AADT – average annual daily traffic;
ARAS – additive ratio assessment;
CRITIC – criteria importance through inter-criteria correlation;
EDAS – evaluation based on distance from average solution;
FUCOM – full consistency method;
MABAC – multi-attributive border approximation area comparison;
MARCOS – measurement alternatives and ranking according to compromise solution;
MCDM – multi-criteria decision-making;
PIPRECIA – pivot pairwise relative criteria importance assessment;
SAW – simple additive weighting;
SSC – Spearman's correlation coefficient;
STDEV – standard deviation;
TOPSIS – technique for order of preference by similarity to ideal solution;
WASPAS – weighted aggregated sum product assessment.

Introduction

The occurrence of hazardous points on two-lane roads is of particular importance in terms of protection of human lives in traffic accidents. Nevertheless, the geometric characteristics of roads on particular sections have a

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major impact on increasing the risk of road accidents. Morency *et al.* (2012) analysed the extent to which road geometry and traffic volume influence social inequalities in pedestrian, cyclist and motorcyclist injuries in wealthy and poor urban areas. Based on their observational study, it was concluded that there were more injured pedestrians, cyclists and motorcyclists at intersections in poorer than in wealthier areas. Nevertheless, the studies have shown that 2 most influential road factors affecting traffic accident rates are pavement conditions and geometric characteristics of the road (Karlaftis, Golias 2002). Based on a study conducted in Western Sweden, statistical analysis show that geometric road characteristics have a significant impact on accident ratio per million vehicle kilometre (Othman, Thomson 2007). This research shows that the ratio increases with increasing the radii of curve (e.g., with left-turn curve radii of less than 100 m, the ratio value is the highest) and that the ratio on downgrades is higher than on upgrades. Based on a study (Mayora, Rubio 2003) conducted at 3.45 km of two-lane road in Valencia (Spain), there was an indication that traffic risk was particularly affected by the density of access points, average sight distance, average speed limit and proportion of no passing zone.

Highway Safety Manual (AASHTO 2010) defines a method of predicting traffic accidents for rural two-lane, two-way roads. The method for predicting traffic accidents for rural two-lane roads provides a structural methodology for estimating the expected average frequency of traffic accidents, accident severity, and the type of traffic accidents for rural two-lane roads with familiar characteristics. The prediction method provides an 18-step procedure for estimating the "expected average number of traffic accidents" (by total number of accidents, accident severity, or type of collision) at a road network, facility, or location.

This paper primarily aims to provide an adequate overview of certain sections of two-lane roads in Bosnia and Herzegovina (Republic of Srpska) and identify their potential risks in terms of traffic indicators. In this regard, it is necessary to determine the impact of the geometric elements of two-lane roads previously described on potential occurrences of risk on particular sections. For this purpose, an original integrated subjective–objective MCDM model has been developed, which includes the application of several methods: the CRITIC, FUCOM and fuzzy PIPRECIA method for determining the significance of the criteria and the MARCOS method for the evaluation of road infrastructure sections.

The rest of the paper is formed through the following sections. In the Section 1 is stated research background. The Section 2 of the paper presents the research procedure with the methodology used and the essential elements of the research described in detail. The Section 3 introduces the formed MCDM model, detailing the input parameters of the model and potential variants. Additionally, the results of the subjective–objective model and their implication are presented. The Section 4 of the paper involves an extensive sensitivity analysis through which the validation of the proposed model is performed. The last section of the paper presents discussion and concluding considerations with guidelines for further research.

1. Literature review

The density of access points is the variable that influences most the rate of head-on and lateral collisions, while sight distance is decisive in run-off the road and single vehicle crashes. High access density has a negative impact on safety. The study was conducted on a sample of 168.20 km of two-lane local rural roads located in Italy (Cafiso *et al.* 2010). Based on a literature review and authors' experience, the features identified as the base parameters for a safety assessment were: curvature (radius, length), tangent length, cross section (lane width and type), access point density and roadside hazard. Based on a report created in Texas (US) (Fitzpatrick *et al.* 2005), using regression analysis, the following variables have been identified to affect traffic accident prediction: AADT, lane width, and segment length. It is particularly significant that, according to the studies conducted (Cafiso *et al.* 2007, 2010; Kulmala 1994; Hadi *et al.* 1995; Baruya 1998), an independent variable that influences the increase of traffic risk in procedures for traffic accident predictions on two-lane roads refers to the total volume of traffic. This value is expressed by AADT. In addition, some studies (Kulmala 1994; Baruya 1998; Mountain *et al.* 1996; Vogt, Bared 1998; Elvik 2008; Harwood *et al.* 2000) highlight the impact of the number of access points on traffic risk prediction, where with their increase, the probability of head-on collisions increases. By the analysis of longitudinal gradient (upgrade/downgrade) as a potential road factor affecting a possible prediction of traffic accidents on two-lane roads, the negative impact of the factor was particularly expressed through one of 12 factors (AASHTO 2010). Each gradient on a rural two-lane and two-way road is an upgrade for one road way and a downgrade for another, and it is given as the 5th factor in the study. Based on 1413 traffic accidents on 85.43 km, a longitudinal downgrade at 6 sections and a potential downgrade value of 1 to 5% as a negative factor affecting a potential occurrence of accidents were analysed. However, there is an indication that the downgrade itself is not a cause of accidents, but a continuous long descending just prior to the accident sites have to be considered (Fu *et al.* 2011). Additionally, a general empirical model of dependence of the number of traffic accidents on the size of traffic flow and real characteristics of road sections is based on a combination of the base model determined from US experience on the one hand and relevant literature data on the other (SOzP 1974). The data are based on negative impacts of other two-lane road elements on the relative increase in the number of accidents compared to two-lane roads with ideal elements. This model primarily depends on the way the access is controlled, the effect of the longitudinal gradient on the number of accidents where an additional lane is required, the radius of horizontal curve and the longitudinal gradient. The model is applied in Serbia. In Finland, Kulmala (1994) investigates the impact of the following independent variables on potential traffic risk: paved width, general speed limit, curve features, average gradient, density of minor accesses, section length and traffic flow. The minimum horizontal curve radius was analysed in a large number of studies – Vogt, Bared (1998); Harwood *et al.* (2000); AASHTO (2010) – as a negative factor affecting a potential probability of traffic accidents. Laboratory research using simulators under different geometries and weather conditions showed that the average driver speed, travel time, collision time and passing the planned distance were influenced by a number of factors related to the road (lane width, average distance, horizontal and vertical curves) as well as weather factors (foggy weather, icy and wet road conditions) (Hamdar *et al.* 2016). In addition to the curve radius, some studies are based on the presence of the barrier and edge lines, as a potential factor affecting the occurrence of traffic accidents under real conditions (Räsänen 2005). Regularly, the number of accidents and the increase in risk are related to the exploitation speed. Exploitation speeds are shown to be higher than design speeds for a speed limit of about 55 m/h or less. Therefore, it is important to demonstrate a potential speed through 5 specific indicators of speed depending on geometric characteristics of the road (Porter *et al.* 2012). Inadequate road infrastructure and increased vehicle inflow on the roads are potential factors affecting an increase in traffic risk of the road transport in Addis Ababa (Ethiopia) (Berhanu 2004). Based on the study (Turner *et al.* 2012) conducted to quantify the impacts of all key road features on the safety of two-lane rural roads in New Zealand, a practical and statistical model was developed. Thus, a total of 10 models were created. The main study used 12 variables from the pilot study. The main study included the following variables: traffic flow (AADT), road width, average absolute gradient, skid resistance coefficient, minimum curve radius, roadside hazard ratings, approach speed, number of access way trips, straight and curve length, regions and mean texture depth. Research based on quantifying the safety effects of highway ramp spacing and other influential highway geometric shapes developed 2 models (Guo 2012): 1st is a development model of the number of accidents as a function of ramp spacing modification factor, and the 2nd is the recommendation of the impact of geometric design elements to reduce the probability of accident occurrence.

As one of the ways to determine the different performance of road infrastructure and determine the state of traffic safety and the field of transport is the use of MCDM methods, which have been shown in the following brief overview. In the research by Kanuganti *et al.* (2017), authors have determined the priority of safety requirements of a certain category of rural roads using SAW method. A number of the same criteria as in this paper on the basis of which the risk is determined and the marking of the section of blackspots was applied by Liu *et al.* (2020). It is a word total number of accidents, (deaths, minor injuries, serious injuries), curve radius on the basis of which the index of ranking of road sections was evaluated using the TOPSIS method. Sections that have index greater than 0.8 were marked as accident blackspots. In addition, TOPSIS method is applied in research by Ruiz-Padillo *et al.* (2016) for considering problems of traffic noise. Different technical solutions on different sections of the road in Spain were evaluated. Structural entropy-TOPSIS model is used by Zhang *et al.* (2018) in order to establish an index system for evaluating the performance of public transport. 4 subsystems were considered: (1) overall development level, (2) infrastructure construction, (3) public transportation service level and (4) policy support. ARAS method has been used in studies by Zagorskas, Turskis (2020) and Hatefi (2018) for setting priority list for construction works of bicycle path segments and selection the best fuel for public transport, respectively. WASPAS method is used by Badalpur, Nurbakhsh (2021) for evaluation risks of a road construction project in Iran, while Khan *et al.* (2020) has been applied for modelling of development of smart city. MABAC, EDAS, and SAW methods are rarely applied than other MCDM method. Subotić *et al.* (2020) have used MABAC method for evaluation locations for roundabout construction, while EDAS method has been used for determining conceptual locations for a park-and-ride parking lot in research by Barauskas *et al.* (2018).

2. Methods

2.1. Proposed methodology

The MCDM methods are widely used for the facilitation of the decision-making process in different fields (Karabašević *et al.* 2019; Zhou *et al.* 2019; Naeini *et al.* 2019). The original MCDM methodology shown in Figure 1 was applied to determine the risk of observed two-lane road sections in Bosnia and Herzegovina.

As part of the 1st phase of the research, data on the geometric characteristics of the road (longitudinal gradient – upgrade/downgrade, arithmetic mean of the number of access points of the analysed sections per kilometre and radii of horizontal curve of the given sections) were collected. In order to obtain an adequate database on sections and to analyse more easily their effects on traffic risk, absolute values of curve radii and longitudinal gradient were used. The values specifically analysed the impact of the fracture of vehicle movement path on the sections and the fracture as a potential indicator of the occurrence of traffic risk.

In addition to the geometric characteristics, data on the available number of traffic accidents (accidents with fatalities, accidents with lightly and seriously injured persons and accidents with material damage) were separately collected as one of potentially consequential traffic indicators. Within the traffic analysis, the values of AADT in the last few available years were also included. It was created a unique database, which represented support for calculations in the further procedure of the model, and especially for entering input parameters. Based on the collected data, the formation of the MCDM model (2nd phase of methodology) was initiated as part of the 1st step of synthesis of the obtained values of geometric and traffic characteristics. A list of 8 criteria, explained in detail later, was created, 9 locations were identified, and an initial decision matrix was formed as an input parameter in the MCDM model. The 3rd phase of methodology consists of 5 steps that are causally linked both to each other and to the elements of the following phase. In this part of methodology, an original integrated objective–subjective model is developed. 1st, the significance of the criteria was determined using individual approaches: CRITIC (Diakoulaki *et al.* 1995), FUCOM (Pamučar *et al.* 2018), and fuzzy PIPRECIA (Stević *et al.* 2018). Subsequently, their aggregation was performed in order to obtain the final criterion values, which were further implemented in the MARCOS method applied to evaluate the alternatives. The advantages of the MARCOS method can be described as follows: consideration of preference points through the ideal and anti-ideal solution at the very beginning of model formation, more precise determination of the degree of utility with respect to both set solutions, proposal of a new way of determining utility functions and its aggregation, possibility to consider a large set of criteria and alternatives. Compared with other methods, this method is simple, effective, and easy to sort and optimize the process. More advantages of this method can be found in research by Stević *et al.* (2020). The CRITIC method belongs to a group of objective methods for determining the weight coefficients of criteria. For that reason, it was used in combination with 2 subjective methods: (1) FUCOM in a crisp form and (2) fuzzy PIPRECIA.

The 4th phase of the methodology involves the validation and sensitivity analysis of the proposed model. It is implemented throughout 4 steps, where the 1st step relates to variations in the significance of the criteria. All individual approaches (linked by the green arrow) are individually included in the calculation of MARCOS method and a comparative analysis is given with respect to the proposed model. The next step includes the comparison of the objective–subjective model with 6 other MCDM methods: MABAC, SAW, EDAS, TOPSIS, WASPAS and ARAS. Finally, the SCC was calculated to determine the correlation of all obtained ranks across previously formed scenarios. In addition, STDEV for all sensitivity analysis scenarios was calculated. Since the CRITIC (Keshavarz Ghorabaee *et al.* 2017; Rostamzadeh *et al.* 2018), FUCOM (Durmić 2019; Badi, Abdulshahed 2019; Fazlollahtabar *et al.* 2019; Noureddine, Ristic 2019) and fuzzy PIPRECIA (Marković *et al.* 2020; Stanković *et al.* 2020; Vesković *et al.* 2020; Tomašević *et al.* 2020; Đalić *et al.* 2020) methods have been exploited in the literature, their detailed algorithms are not presented. In the following section, only the steps and explanations of the MARCOS method (Stević *et al.* 2020; Puška *et al.* 2020) are given in detail.

2.2. MARCOS

The MARCOS method is performed through the following steps (Stević *et al.* 2020).

Step 1: Formation of an initial decision-making matrix. Multi-criteria models include the definition of a set of n criteria and m alternatives. In the case of group decision-making, a set of r experts should be formed to evaluate alternatives according to the criteria. In the case of group decision-making, expert evaluation matrices are aggregated into an initial group decision-making matrix.

Step 2: Formation of an extended initial matrix. In this step, the extension of the initial matrix is performed by

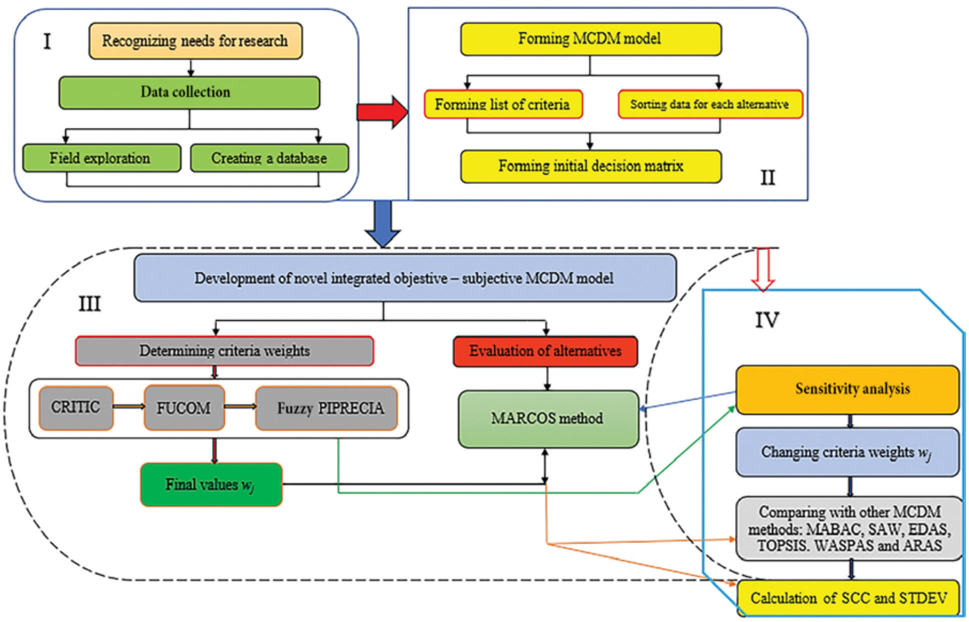


Figure 1. Applied methodology for the evaluation of two-lane road sections in terms of traffic risk

defining the ideal AI and anti-ideal AAI solution:

$$X = \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ AAI & x_{aa1} & x_{aa2} & \cdots & x_{aan} \\ A_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ A_2 & x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ A_m & x_{m1} & x_{22} & \cdots & x_{mn} \\ AI & x_{ai1} & x_{ai2} & \cdots & x_{ain} \end{matrix}. \quad (1)$$

The AAI is the worst alternative, while the AI is an alternative with the best characteristic. Depending on the nature of the criteria, AAI and AI are defined by applying Equations (2) and (3):

$$AAI = \begin{cases} \min\limits_i x_{ij}, & \text{if } j \in B; \\ \max\limits_i x_{ij}, & \text{if } j \in C; \end{cases} \quad (2)$$

$$AI = \begin{cases} \max\limits_i x_{ij}, & \text{if } j \in B; \\ \min\limits_i x_{ij}, & \text{if } j \in C, \end{cases} \quad (3)$$

where: B represents a benefit group of criteria; C represents a group of cost criteria.

Step 3: Normalization of the extended initial matrix **X**. The elements of the normalized matrix $\mathbf{N} = \left[n_{ij}\right]_{m \times n}$ are obtained by applying Equations (4) and (5):

$$n_{ij} = \frac{x_{ai}}{x_{ij}}, \text{ if } j \in C; \quad (4)$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}}, \text{ if } j \in B, \quad (5)$$

where: x_{ij} and x_{ai} represent the elements of the matrix **X**.

Step 4: Determination of the weighted matrix $\mathbf{V} = \left[v_{ij}\right]_{m \times n}$. The weighted matrix **V** is obtained by multiplying the normalized matrix **N** with the weight coefficients of the criterion w_j:

$$v_{ij} = n_{ij} \cdot w_j. \quad (6)$$

Step 5: Calculation of the utility degree of alternatives K_i. By applying Equations (7) and (8), the utility degrees of an alternative in relation to the anti-ideal and ideal solution are calculated:

$$K_i^- = \frac{S_i}{S_{aai}}; \quad (7)$$

$$K_i^+ = \frac{S_i}{S_{ai}}, \quad (8)$$

where: $S_i\left(i = 1, 2, ..., m\right)$ represents the sum of the elements of the weighted matrix **V**:

$$S_i = \sum_{i=1}^{n} v_{ij}. \quad (9)$$

Step 6: Determination of the utility function of alternatives $f\left(K_i\right)$. The utility function is the compromise of the observed alternative in relation to the ideal and anti-ideal solution. The utility function of alternatives is defined by equation:

$$f\left(K_i\right) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f\left(K_i^+\right)}{f\left(K_i^+\right)} + \frac{1 - f\left(K_i^-\right)}{f\left(K_i^-\right)}}, \quad (10)$$

where: $f\left(K_i^-\right)$ represents the utility function in relation to the anti-ideal solution; $f\left(K_i^+\right)$ represents the utility function in relation to the ideal solution.

Utility functions in relation to the ideal and anti-ideal solution are determined by applying Equations (11) and (12):

$$f\left(K_i^-\right) = \frac{K_i^+}{K_i^+ + K_i^-}; \quad (11)$$

$$f\left(K_i^+\right) = \frac{K_i^-}{K_i^+ + K_i^-}. \quad (12)$$

Step 7: Ranking the alternatives. Ranking the alternatives is based on the final values of utility functions. It is desirable that an alternative has the highest possible value of the utility function.

3. Case study

In order to determine the degree of risk on the roads in Bosnia and Herzegovina through the observed sections, a list of 8 criteria was formed on the basis of which the evaluation was carried out. The analysis was conducted on 9 sections of two-lane main roads of the 1st order in Bosnia and Herzegovina as a potential alternative (Table 1).

3.1. Forming MCDM model

The following are the starting points for the potential criteria affecting traffic risk:

- »» AADT from 2010 to 2015 (C1);
- »» the number of traffic accidents with fatalities (C2);
- »» the number of traffic accidents with slightly injured persons (C3);
- »» the number of traffic accidents with seriously injured persons (C4);

Table 1. Sections of two-lane main roads of the 1st order – potential alternatives

Alternative label	Section	Section label	Section length [km]
A1	Doboj Novi – Doboj (Poljice)	110	1.469
A2	Doboj (Poljice) – Border RS – FBiH	110	2.945
A3	Doboj – Border RS – FBiH (Karuše)	105	3.517
A4	Rudanka – Doboj	105	7.405
A5	Johovac – Rudanka	105	6.854
A6	Klupe – Teslić (Barići)	110	16.734
A7	Obodnik – Klupe	110	20.134
A8	Šešlije – Johovac	105	4.701
A9	Teslić (Barići) – Border RS – FBiH	110	6.646

- »» the number of traffic accidents with material damage (C5);
- »» a longitudinal gradient (upgrade/downgrade) (C6);
- »» a minimal horizontal curve radius on each section (C7);
- »» the number of access points on each section (left and right) (C8).

The paper analyses 5 variables (AADT and number of traffic accidents) and 3 fixed criteria. AADT is the average traffic value in the available 5 years. The number of traffic accidents for all 3 classes has been taken from the sample for (2015–2018) 4 years. For simplicity, the absolute values of fixed criteria C6 and C7 are accepted.

This study is part of the research done in Bosnia and Herzegovina at road length 70.405 km divided into 9 different sections. After that, each section is considering independent with dividing on small sections length 200…800 m, which are the focus of other future research. In order to determine the degree of risk on the roads in Bosnia and Herzegovina through these sections (length 70.405 km), a list of 8 criteria was formed on the basis of which the evaluation was carried out. The analysis was conducted on 9 sections of two-lane main roads of Category I in Bosnia and Herzegovina as a potential alternatives. Alternatives A6 and A7 are long and mountainous sections.

In this section, the results obtained by the methodology described above are presented. In order to treat the results adequately, it is necessary to describe in detail the initial decision matrix (Table 2) that consists of 9 alternatives, i.e. sections of two-lane roads described in Table 1.

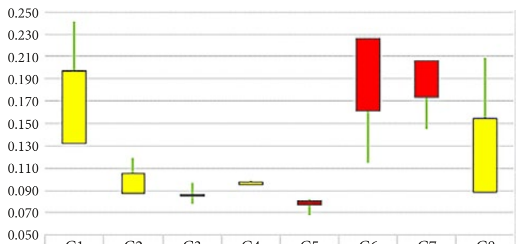
All the criteria except the 7 belong to the group of benefit criteria that need to be maximized. This orientation and criterion types have been taken into account for the reason that the sections are evaluated in terms of risk, where the sections should be ranked starting from the section with the highest risk to the section with the lowest risk. The 7 criterion should be minimized since the lowest value indicates a sharp curve of the road, which most influences the occurrence of risk.

3.2. Determining criteria weights by CRITIC, FUCOM and fuzzy PIPRECIA

Figure 2 presents the results of the integrated model for determining the significance of the criteria. As already emphasized, 3 different approaches have been applied:

- »» CRITIC;
- »» FUCOM;
- »» fuzzy PIPRECIA.

It is important to note that CRITIC is a method that objectively calculates the weights of criteria, therefore without any decision-makers' preferences. For this reason, different values can be observed with respect to the other 2 subjective methods for determining the significance of the criteria. The most significant criterion according to the objective approach is the 6 criterion, i.e. road gradient, while according to both objective approaches, the most significant criterion is the 1st criterion, i.e. AADT, which is expected in a way. It is for these reasons that different approaches combining objective and subjective approaches have been taken into account since decision-makers' preferences based on their experience are unavoidable in such research. The 2nd most significant criterion according to the CRITIC method is the radius of the section and the 3rd is AADT. Other criteria are less significant as shown in Figure 2. When it comes to applying the other 2 methods that are subjective, it can be observed that the



	C1	C2	C3	C4	C5	C6	C7	C8
CRITIC	0.132	0.087	0.085	0.095	0.080	0.227	0.206	0.088
FUCOM	0.218	0.109	0.078	0.099	0.068	0.115	0.145	0.168
Fuzzy PIPRECIA	0.241	0.119	0.097	0.099	0.082	0.141	0.171	0.209
Final w_j	0.197	0.105	0.087	0.098	0.077	0.161	0.174	0.155

Figure 2. Criteria weights using 3 different methods and final criteria weights

Table 2. Initial decision matrix

	C1	C2	C3	C4	C5	C6	C7	C8
A1	10350.667	0	2	1	16	0.771	500.700	5.63
A2	7529.500	0	27	3	40	0.829	619.077	11.07
A3	13982.333	1	26	7	70	0.235	1632.286	12.50
A4	13191.333	6	52	18	198	0.503	1662.393	35.39
A5	8090.833	1	18	11	49	0.145	678.500	19.12
A6	6244.500	2	23	10	43	0.730	1431.169	21.31
A7	3899.500	1	1	0	2	1.040	720.717	9.46
A8	7749.500	0	4	4	34	0.191	2575.067	10.00
A9	8668.500	0	17	8	24	0.415	1291.355	20.29
	max	max	max	max	max	max	min	max

rankings of the criteria are identical with certain differences in values. By averaging the values of the criteria obtained by applying all 3 approaches, the final rankings are obtained: C1 > C7 > C6 > C8 > C2 > C4 > C3 > C5 and the values of criteria: C1 = 0.197; C2 = 0.105; C3 = 0.087; C4 = 0.098; C5 = 0.077; C6 = 0.161; C7 = 0.174; C8 = 0.155.

3.3. Obtained results by MARCOS method

After applying the MARCOS method, the final results for 9 observed sections were obtained (Table 3). The section with the highest risk is the Rudanka – Doboj section (A4), which represents a section of the road infrastructure of the 105 road. The greatest risk of the section is reflected by its individual indicators. Namely, out of 8 criteria for the evaluation of the alternatives, 5 criteria (4 criteria related to traffic accidents and one to the number of access points per km) indicates that this section has undesirable values. It can be clearly seen from Table 3 that there is a significant difference in the final values of the Rudanka – Doboj section (0.783) and other sections (>0.200). It is important to point out that the sections Doboj (Poljice) – Border RS – FBiH (A2) and Klupe – Teslić (Barići) (A6) have almost identical values and it can be concluded that they can change their positions depending on the slightest change of parameter values or the application of another approach. A similar situation is with alternatives A1, A5 and A3. These alternatives have difference in values between 0.004 and 0.011, so can be concluded that they have approximately equal risk. Alternatives A7 and A8 have the smallest values, 0.372 and 0.241, respectively, so can be concluded that these sections have good performance and represent the most safety sections.

4. Sensitivity analysis and discussion

This section validates previously obtained results of the impact of key traffic indicators on existing risk. The section is divided into 4 subsections. In the 1st subsection, the sensitivity of the model to changes in criterion values is observed, and in the 2nd, a comparison with 6 other MCDM methods is made. The 3rd subsection refers to the calculation of the SCC used to determine the correlations of initial and other ranks. The last subsection of the sensitivity analysis determines the STDEV of the calculated values of criteria and ranks obtained by different methods.

4.1. Sensitivity analysis of model to changes in the weight coefficients of the criteria

In this part of the validation of the previously obtained results, the model is recalculated using the MARCOS method, but for different criterion values. The values obtained by individual methods are used, as shown in Figure 3.

Figure 3 shows the results of the sensitivity analysis in relation to different weight values of the criteria. The Rudanka – Doboj section continues to be the section with the highest risk. Applying the CRITIC–MARCOS model, the value of this section is reduced, and thus the degree of risk. Applying the significance of the criteria obtained by fuzzy PIPRECIA and FUCOM methods, the final value of this section increases, which means that the risk increases, too. Alternative A1 does not significantly change its final values, a maximum decrease of 0.021 and increase of 0.046. The situation is similar for other alternatives, but it is important to note that the alternatives change their ranks since, depending on the method used to calculate the alternatives, some values increase while others decrease, resulting in certain changes, which are explained in more detail in Figure 4.

Figure 4 shows the change in rankings of the sections in relation to different approaches for determining the significance of the criteria. The most hazardous is the 4th alternative regardless of the approach taken. When it comes to the alternative with the least risk for traffic participants, it is the 8th alternative that also retains complete consistency regardless of the method used. Using the CRITIC–MARCOS model, the 2nd section retains its 2nd position, while using the FUCOM–MARCOS and fuzzy PIPRECIA–MARCOS model, it occupies the fifth position, which means that changing the significance of the criteria, especially AADT, affects the final degree of risk.

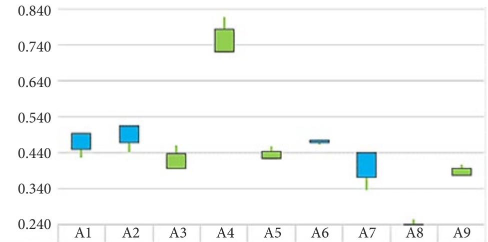
Table 3. Final results obtained by proposed methodology

	S_i	K_i^-	K_i^+	$f(K^-)$	$f(K^+)$	K_i	Rank
AAI	0.138	1.000	–	–	–	–	–
A1	0.479	3.460	0.455	0.878	0.122	0.448	4
A2	0.500	3.614	0.475	0.878	0.122	0.468	2
A3	0.468	3.379	0.444	0.878	0.122	0.437	6
A4	0.837	6.051	0.795	0.878	0.122	0.783	1
A5	0.475	3.432	0.451	0.878	0.122	0.444	5
A6	0.499	3.609	0.474	0.878	0.122	0.467	3
A7	0.398	2.875	0.378	0.878	0.122	0.372	8
A8	0.258	1.865	0.245	0.878	0.122	0.241	9
A9	0.424	3.062	0.402	0.878	0.122	0.396	7
AI	1.053	–	1.000	–	–	–	–

By these 2 models, the 3rd section occupies the 3rd position, while using the CRITIC–MARCOS, it occupies the 7th position, and it is in the 6th position by applying the objective–subjective model. The situation is similar with alternatives A1, A5, and A6, while alternatives A7 and A9 change their positions only when the CRITIC–MARCOS model is applied.

4.2. Comparison with other MCDM models

This section compares 6 other MCDM methods: SAW (Biswas *et al.* 2019), ARAS (Zavadskas, Turskis 2010), WASPAS (Zavadskas *et al.* 2012), EDAS (Keshavarz Ghorabaee *et al.* 2015), MABAC (Pamučar, Ćirović 2015), and TOPSIS (Hwang, Yoon 1981).



	A1	A2	A3	A4	A5	A6	A7	A8	A9
CRITIC–MARCOS	0.494	0.515	0.395	0.722	0.424	0.473	0.441	0.218	0.377
FUCOM–MARCOS	0.426	0.443	0.460	0.814	0.455	0.463	0.336	0.253	0.405
Fuzzy PIPRECIA–MARCOS	0.427	0.449	0.455	0.810	0.452	0.465	0.344	0.251	0.405
MARCOS	0.448	0.468	0.437	0.783	0.444	0.467	0.372	0.241	0.396

Figure 3. Results of SA using various criterion weight approaches

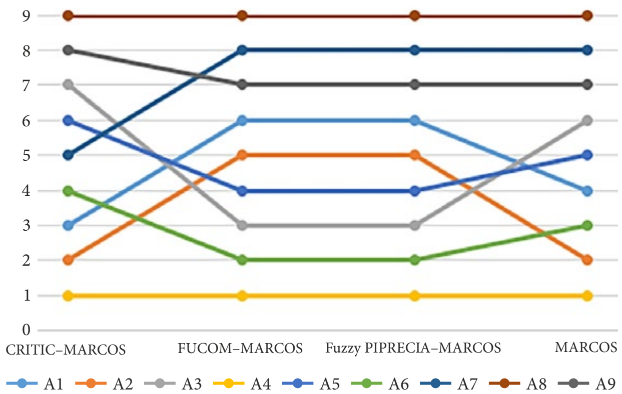


Figure 4. Results of sensitivity analysis – ranks depending on different methods for determining criterion weights

The applied subjective–objective model in comparison with other methods shows different ranks as given in Figure 5. It is important to emphasize that the 1st-ranked alternative A4 and the last-ranked A8 do not change their positions regardless of the approach taken. The 7th alternative, only by applying the TOPSIS method, occupies the 7th position, while it is in the penultimate 8th position by applying the other methods. Alternative A9 is in the 8th position using the TOPSIS method and in the 6th using the EDAS method, while it is in the 7th position with the other methods. The 6th section of road infrastructure is ranked 3rd using the MARCOS and SAW methods, while it is 2nd using the other methods. As noted above, the reason for this is the almost identical value in the methodology applied. The 5th alternative occupies the 5th position by applying MARCOS, MABAC and SAW methods, while it is in the 3rd position in the rankings of other methods. Alternative A3 changes its position from the 4th to the 6th. The greatest changes in the ranks are observed for the 1st and 2nd sections of the road, which change their ranks by 3 positions.

The presented low differences in results obtained using other MCDM methods, do not limit the usefulness of the study, as it is impossible to know in advance the possible outcomes of an applied methodology and the extent of possible deviation of the rankings, therefore making the process is significant for validation. The main reason for difference in ranking can be different normalization process in various MCDM methods.

4.3. Calculation of statistical correlation test

This part of sensitivity analysis is concerned with determining the rank correlation using a statistical test, i.e. the SCC. The correlation coefficient for both types of sensitivity analysis is calculated: for the ranks obtained by changing the significance of the criteria and for the ranks obtained through comparison with other methods. When calculating the SCC for the ranks with changes in criterion weights, the model applied has the following SCC values: a correlation value of 0.8 with fuzzy PIPRECIA–MARCOS and FUCOM–MARCOS, and 0.833 with CRITIC–MARCOS, which represents a high correlation according to Stević *et al.* (2019).

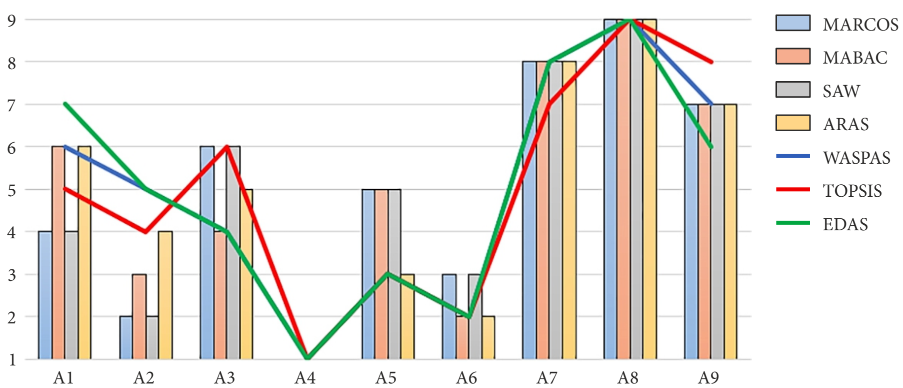


Figure 5. Ranks of the alternatives using different methods

Table 4. SCC for the obtained ranks using different methods

	MARCOS	MABAC	SAW	ARAS	WASPAS	TOPSIS	EDAS	AV
MARCOS	1.000	0.917	1.000	0.883	0.817	0.900	0.767	0.898
MABAC	–	1.000	0.917	0.950	0.933	0.900	0.917	0.936
SAW	–	–	1.000	0.883	0.817	0.900	0.767	0.873
ARAS	–	–	–	1.000	0.983	0.967	0.967	0.979
WASPAS	–	–	–	–	1.000	0.933	0.983	0.972
TOPSIS	–	–	–	–	–	1.000	0.883	0.942
EDAS	–	–	–	–	–	–	1.000	1.000
TOPSIS	–	–	–	–	–	–	–	1.000
								0.950

Table 4 shows the values of the correlation coefficients for individual ranks and finally the total SCC. The total average SCC is 0.950, which represents an extremely high correlation, so it can be concluded that the model used, i.e. the results obtained are valid. It is important to note that MARCOS and SAW have full correlation, which means that there is no change of ranks. MARCOS and MABAC have a SCC of 0.917, while MARCOS with ARAS has a correlation value of 0.833, WASPAS 0.817, TOPSIS 0.900, while the lowest correlation of 0.767 is with the EDAS method.

4.4. Calculation of STDEV for the obtained ranks

The following section provides the calculation of STDEV for all previously obtained ranks.

Figure 6 shows the STDEV of the ranks. The left side of the chart labelled number one indicates a deviation in alternative rankings by changing criterion weights. Taking into account all the above regarding all the methods for determining the significance of the criteria, it is understandable that STDEV goes up to 2.062 and refers to the ranking of the 3rd alternative. The deviation for alternative A2 is 1.732, and for alternatives A1 and A7 is 1.500. For other sections of the road, the deviation is less than one, and it is important to emphasize that there are no deviations at all for alternatives A4 and A8 since they are constant ranks. The right side of the chart shows the calculated STDEV for the ranks obtained using different methods. By observing these values, it can be noticed that the STDEV is much lower compared to the rankings obtained by varying the criterion weights. It is important to note that the maximum deviation is 1.272, and that the deviation is less than one for most alternatives, while the deviation is zero for the 1st-ranked and last-ranked alternative. Practically, it can be concluded that the impact of the criteria plays a significant role in obtaining the results, i.e. the rankings of alternatives, and deviations in the results.

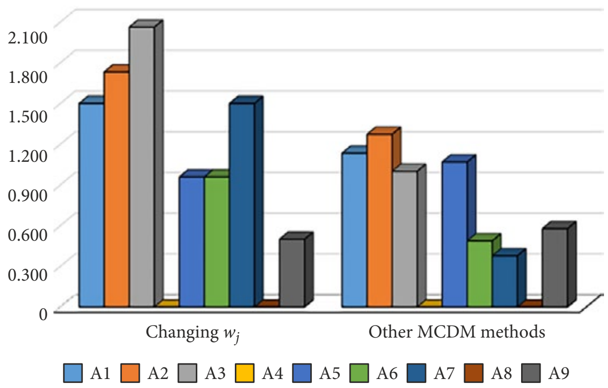


Figure 6. STDEV of the ranks through the scenarios

Conclusions

The conducted research on 9 sections of main roads and their analysis in terms of traffic risk resulted in valid data on identifying the critical section of main roads by comparing the values of criteria and alternatives. Using the given methods, an objectively hazardous section Rudanka – Doboj was obtained, while the section with the least risk was Šešlije – Johovac. Such result is caused by the fact that section Rudanka – Doboj has an undesirable value taking into account almost all factors. An adequate reaction in terms of increasing surveillance and traffic safety in this section is required. The most important contributions of this research are related to the creation of a novel and original subjective–objective model for the evaluation of road infrastructure sections and determination of traffic risks on the sections. The aim of the proposed model is to take the advantages of partial methods and allow for more accurate and balanced decision-making through their integration. 9 different sections of traffic infrastructure were evaluated on the basis of 8 criteria including a combination of geometric elements of the road, AADT and traffic safety indicators. Each of the 9 sections was analysed every 200 m, the parameters were individually determined, and after being entered into the database, they were integrated and aggregated for the purposes of this paper. After the initial decision matrix was formed, an integrated novel model was demonstrated. 3 methods were applied to determine the significance of the criteria for the evaluation of alternatives. The aggregation of criterion values obtained by applying individual methods resulted in final criterion values. Subsequently, the MARCOS method for the evaluation of traffic infrastructure sections was applied ranking the sections from the most to the least hazardous one. Then, the validation of the results through changes in the significance of the criteria was performed and it was found that the model was sensitive when the values of the criteria changed. The validation of the results was also presented by comparison with 6 other MCDM methods, which led to the conclusion that no significant changes in the model results occurred. This is confirmed by the calculated SCC, which indicates an extremely high correlation of 0.950. In addition, the STDEV was determined for all applied approaches, i.e. ranks of the alternatives by the given approaches. A large number of access points per kilometre (35.4) and high frequency of AADT have an extremely huge impact on the occurrence of risk and side effects such as traffic accidents of different severity. The obtained results in terms of risk can be used for improving road safety. The results can help decision-makers take into account these indicators as an input parameter for planning road infrastructure.

In the forthcoming period, it is necessary to carry out a detailed field recording of the number of access points on all sections of two-lane roads in Bosnia and Herzegovina that are not part of this research, and form a unique database of their number at the same time. It is also necessary to introduce a much larger sample of input parameters (AADT and the number of traffic accidents by classes), which would improve the precision of the conducted research. These indicators should be an input parameter of all planning, design and operational analyses, as well as indicators for the development of regulatory plans for a given area in local conditions.

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