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RANKING DANGEROUS SECTIONS OF THE ROAD USING THE MCDM MODEL

Dragana Nenadić[1]

[1]University of East Sarajevo, Faculty of Transport and Traffic Engineering Doboj, Bosnia and Herzegovina

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Abstract: *Traffic accidents are a matter of great concern in traffic safety since they unexpectedly and sometimes unavoidably cause fatal and non-fatal injuries, or material damage. The causes of traffic accidents can vary but they can always be linked to one of the four basic factors: human, vehicle, road and environment. However, there are some places where traffic accidents happen more frequently than in others. The decision-making process concerning dangerous road sections using the Multi-criteria decision-making (MCDM) model involves the definition of quantitative and qualitative traffic safety criteria. The model used in the paper consists of five quantitative and two qualitative traffic safety criteria. Based on those criteria the ranking of the prospected sections is carried out. By analyzing the total number of traffic accidents, by their categories and by analyzing the current state of the traffic infrastructure and Annual Average Daily Traffic (AADT), seven traffic safety criteria are defined and, in the first phase of the model, are rated and ranked by their importance. By using the Full Consistency Method (FUCOM), weighted coefficients of the defined criteria are determined followed by ranking of dangerous road sections using the Weighted Aggregate Sum Product Assessment method (WASPAS). The obtained results show which of the offered alternatives is best ranked, that is, which section of the road is the safest one.*

Key Words: *Dangerous Sections, Traffic Safety, Multi-criteria Decision-making, FUCOM, WASPAS*

1. Introduction

Undoubtedly, decision-making is one of the most important aspects of shaping the future of traffic safety, especially in situations where human lives and material goods are endangered, as in the case of traffic accidents. The multi-criteria decision-making (MCDM) methods are gaining importance as potential tools for analyzing and solving

* Corresponding author.
E-mail addresses: dragana_95_@hotmail.com (D. Nenadić)

complex real-time problems due to their inherent ability to evaluate different alternatives with respect to various criteria (Chakraborty et al., 2015). The multi-criteria decision-making methods can be used as an adequate tool for making valid decisions when it comes to traffic safety. Approximately 1.35 million people die each year as a result of road traffic accidents. Variations in death rates observed across regions and countries also correspond to differences in the types of road users most affected. Only in the European Union, over 1.1 million traffic accidents have killed more than 30,000 people while 1.5 million people have been injured (World Health Organization, 2018). Based on WHO data (2018), estimated road traffic death rate in Bosnia and Herzegovina is 17.7 (per 100 000 population).

For the system management, it is necessary (Lipovac, 2008):

- to know the existing state of affairs,
- to define the desired condition, and,
- to choose those management measures that would bring the existing situation closer to the desired one.

In the field of traffic safety, the concept of management can be defined similarly; so, in order to manage the safety of traffic, it is necessary to know the existing situation, define the desired state of affairs and take measures to bring the existing state to the desired one. In defining the present state of affairs, it is necessary to observe the basic trends in the development of the phenomenon, which includes the prognosis of the occurrence based on the existing condition (for example, the forecast of the number of traffic accident and their consequences, assuming that the current trend continues). This means that nothing is done in terms of solving traffic safety problems, so that the current trend continues. However, this is only the first step in defining the current state. It should be followed by the research based on the definition of the supposed desired state as well as the selection of those management measures that would bring the current state closer to the desired one.

Because of that, traffic safety includes several models that can be used for defining the current state of affairs (Lipovac, 2008):

- Descriptive model,
- Prediction model,
- Risk factor model,
- Models that show the consequences of traffic accidents, and,
- Models that rely on monitoring the traffic safety indicators.

The descriptive model is trying to describe the state of affairs and traffic safety problems by using three dimensions: exposure, accident risk and consequences of traffic accidents. Basic data about road traffic accidents and injuries are collected every day in most countries. Police officers write reports on accidents, insurance companies document their clients' accidents while health workers keep medical records on the road traffic injuries they have treated. The main purpose of documenting this information is usually to assist an agency in carrying out its specific function like investigation, law enforcement and provision of health care. However, this information can also be used for ranking dangerous sections of the road by using the MCDM model.

The motorization rate in Bosnia and Herzegovina has been growing gradually in the last couple of years and so has the number of road accidents. The consequence of such trend is the absence of the road safety system due to the lack of systemic and continual road safety management (Lipovac et al., 2015). Ranked road sections in terms of risk, together with ranked weights of factors considered as causes of accidents for each section, are highly effectual information for road safety implementing planning (Jantakat et al., 2014). That is why it is important to determine the dangerous road sections, which can help us to make a better decision when it comes to improving traffic safety.

Basic sources about traffic accidents and their consequences are police, hospital and insurance company reports. So, the first step in the descriptive model is to describe the current state of affairs and determine the importance of the traffic safety problems based on that data.

In this paper, the description of the current state of affairs is given by data on the total number of traffic accidents - by their categories, data on the current state of the traffic infrastructure and AADT for observed locations. In order to determine the significance of the problem, dangerous road sections on the territory of the municipality of Derventa will be ranked by using the MCDM model. Hence the main goal of this paper is to make a decision about the road section which is estimated as the most dangerous of all the observed ones. That will show the significance of the problem when it comes to traffic safety.

The paper is structured in several sections. Section 1 (*Introduction*) shows the importance of describing the current state of affairs when it comes to traffic safety. Next Section (*Literature review*) consists of three parts: a review of the use of the Multi-Criteria Decision-Making model, a review of the use of the FUCOM method in different research fields and a review of the use of the WASPAS method of evaluating different alternatives. Section 3 (*Methods*) consists of two parts; the first one describes in detail three steps of the FUCOM method while the second one describes the WASPAS method by its steps. It is on the basis of these steps that the dangerous sections of the road on the territory of the Municipality of Derventa will be ranked. The main section of the paper is Section 4 (*Case study*), which includes forming a multi-criteria model as well as applying the FUCOM and the WASPAS methods to the concrete case. The end of this Section is reserved for the sensitivity analysis, based on what we can do in the model behavior testing. The last section of the paper (*Conclusion*) represents a brief summary of the things described in the paper as well as an explanation showing us which of the observed locations is ranked best.

2. Literature review

The research and development of the MCDM methods increased during the 80s and early 90s but it seems that the exponential growth of this process continued (Köksalan et al., 2011). The MCDM methods can be applied effectively to determining the value and utility degree of various areas and to establishing the priority order for their implementation (Turskis, 2008). Triantaphyllou and Mann (1995) said that the MCDM plays an important role in real-life problems as there are a large number of everyday decisions to be made which include a huge number of the criteria. According to Chen et al. (2015), the MCDM is an effective, systemic and quantitative way of solving vital real-life problems with a large number of alternatives and several (opposing) criteria. According to Drezner (1995) the study of location selection has a long and extensive history spanning many general research fields including operations research (or management science), industrial engineering, geography, economics, computer science, mathematics, marketing, electrical engineering, urban planning, etc. According to Kahraman et al. (2011) evaluation of specific sites in the selected community is commonly termed microanalysis. Many authors (Roberts and Goodwin, 2002; Solymosi and Dompi, 1985; Cook, 2006; Weber and Borcherding, 1993) agree that the values of criteria weights are significantly conditioned by the methods of their determination. But there is no agreement as to which of the methods is the best one for determining criteria weights. According to Stević et al. (2018) the main problem of the multi-criteria decision-making (MCDM) is that of choosing an appropriate method for determining criteria weights, as a very important stage, which complicates the decision-making process. If we take the fact that the weights of criteria can significantly influence the outcome of the decision, it is clear that attention must be paid to the objectivity factors of criteria weights.

Real problems do not usually have the criteria of the same degree of significance. It is, therefore, necessary that the significance factors of particular criteria should be defined by using appropriate weight coefficients for the criteria, so that their sum is one. Therefore, the new FUCOM method for determining the weight coefficients of criteria is proposed (Pamučar et al., 2018). The FUCOM method enables the precise determination of the values of the weight coefficients of all of the criteria at a certain level of the hierarchy. In comparison with similar subjective models (the AHP and the BWM methods) for determining the weight the coefficients of the criteria, the FUCOM only requires the (n-1) pairwise comparison of the criteria (Pamučar et al., 2018).

A FUCOM method is applied to determining the weights of the criteria for the selection of the Automatically Guided Vehicles (AGVs) as one important type of material handling equipment in warehouses. The multi-criteria model included several criteria and AGVs solutions, based on which the selection of AGVsis done. That caused reduction of labor costs, increased reliability and productivity, reduction of the damage of goods, safety improvement, managing and control of the complete system, etc. (Zavadskas et al., 2018).

Solving different problems can be done by using the FUCOM with some other method. The advantages of the new methodology, Delphi-FUCOM-SERVQUAL methodology, are reflected in providing precise treatment of input and output parameters, and obtaining results that are more objective (Prentkovskis et al., 2018). According to Nunić (2018), solving the problem of the selection of the PVC carpentry manufacturer by using the FUCOM-MABAC model has included all the relevant criteria which are of influence upon the final decision. The objective was to obtain the most suitable offer, that is, the one which involves high quality, which is the lowest possible price, a short time for delivery and montage, a possibility of deferred payment, a longer warranty period with the manufacturer's reliability but it is not necessary to ignore other relevant facts that may have an impact on the formation of a final decision. According to Pamučar et al. (2018) the FUCOM method was used for evaluation of the level crossing, as a point of the crossing of road and rail traffic in the same level. The presented FUCOM-MAIRCA model allows consideration of subjectivity in the process of group decision-making through linguistic evaluation of the evaluation criteria.

The results obtained using the WASPAS method show that the use of method and techniques in the field of MCDM can help decision-makers to successfully evaluate defined alternatives (Tešić et al 2018). Chakraborty and Zavadskas (2014) used the WASPAS approach for solving decision-making problems related to manufacturing, and the findings of this paper were accurate; the proposed method had accurate ranking capability for solving decision-making problems related to manufacturing. According to Zavadskas et al. (2012), the WASPAS method approach enables attaining high accuracy measurement.

The use of the WASPAS technique for assessment and selection of appropriate solutions for occupational safety (Dėjus and Antuchevičienė, 2012) has revealed that typical solutions for occupational safety are used in the field of road construction; however, they are intended for protecting third persons from accessing dangerous zones next to a construction site rather than for ensuring health and safety of workers.

According to Stević et al. (2018) the expanded form of WASPAS method, which includes rough numbers, was used to make decisions that are more precise because an initial matrix has more accurate values, which eliminates subjectivity and reduces uncertainty in a decision-making process. That is why the complete Rough BMW-Rough WASPAS model is used for the location selection for the construction of a roundabout which is one of the essential factors for increasing mobility in the towns.

3. Methods

3.1 Full Consistency Method (FUCOM)

The FUCOM method was developed by Pamučar et al. (2018) for determining the weights of criteria. According to the author, this new method is better than AHP (Analytical Hierarchy Process) and BWM (Best Worst Method).

The FUCOM provides a possibility to validate the model by calculating the error size for obtained weight vectors, by determining the degree of consistency. On the other hand, in other models for determining the weights of criteria, the BWM (Rezaei, 2015) and the AHP (Saaty, 1980) models, redundancy in pairwise comparison appears which makes them less susceptible to errors in judgment, while the methodological procedure of the FUCOM eliminates that problem.

In the following section, the procedure for obtaining weight coefficients of criteria by applying the FUCOM is presented:

Step 1 In this 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:

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

Step 2 In this step, comparison of the ranked criteria is carried out and comparative priority $(\varphi_{k/(k+1)}) = \frac{C_k}{C_{k+1}}$, $k=1,2,...,n$, with k representing the rank of the criteria) of the evaluation criteria, is determined.

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

Step 3 In this step, the final values of the weight coefficients of evaluation criteria $(w_1, w_2, ..., w_n)^T$ are calculated. The final values of the weight coefficients should satisfy the following two conditions:

(a) The ratio of the weight coefficients is equal to the comparative priority among observed criteria $(\varphi_{k/(k+1)})$ defined in Step 2, i.e. the following condition is met:

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

(b) In addition to condition (2), the final values of the weight coefficients should satisfy the condition of mathematical transitivity, i.e. t $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$.

Then $\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$ $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ are obtained.

Thus, another condition that the final values of the weight coefficients of the evaluation criteria should meet is obtained, namely:

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

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

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

By solving model (5), we obtain the final values of evaluation criteria $\left(w_1, w_2, ..., w_n\right)^T$ and the degree of consistency (χ) of the results obtained.

3.2. Weighted aggregate sum product assessment method (WASPAS)

The Weighted aggregate sum product assessment method (WASPAS) (Zavadskaset al., 2012) is one of the best known and often applied multiple criteria decision-making methods for evaluating a number of alternatives in terms of a number given criteria. In general, suppose that a given MCDM problem is defined on *m* alternatives and *n* decision criteria. Next, suppose that w_j denotes the relative significance of the criterion and x_{ij} is the performance value of alternative *i* when it is evaluated in terms of criterion *j*.

WASPAS methods consist of the following steps:

Step 1 Formatting of initial decision matrix (X). The first step is to evaluate *m* alternatives by *n* criteria. Alternatives are shown to the vectors:

$$A_i = \left(x_{i1}, x_{i2}, ..., x_{in}\right)$$

Where x_{ij} is value of i-th alternatives according to the j-th criterion.

$\left(i = 1, 2, 3, ..., m;\ j = 1, 2, 3, ..., n\right)$.

$$X = \begin{array}{c} \\ A_1 \\ ... \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & ... & C_n \end{array} \\ \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \end{array} \tag{6}$$

Step 2 In this step it is necessary to normalize the initial matrix using the following equations:

$$n_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \tag{7}$$

for $C_{1,} C_2, ..., C_n \in B$.

$$n_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \tag{8}$$

for $C_{1,} C_2, ..., C_n \in B$.

Step 3 Weighing the normalized matrix is done in such a way that the previous (normalized) matrix is multiplied by the weight coefficients:

$$V_n = \left[v_{ij} \right]_{m \times n} \tag{9}$$

$$V_{ij} = w_j \times n_{ij}, i = 1, 2, ..., m, j \tag{10}$$

Step 4 Summarizing all obtained values of the alternatives (summation in rows):

$$Q_i = \left[q_{ij} \right]_{1 \times m} \tag{11}$$

$$q_{ij} = \sum_{j=1}^{n} v_{ij} \tag{12}$$

Step 5 Determination of the weighted product model by using the following equations:

$$P_i = \left[p_{ij} \right]_{1 \times m} \tag{13}$$

$$p_{ij} = \prod_{j=1}^{n} (v_{ij})^{wj} \tag{14}$$

Step 6 Determination of the relative values of alternative A_i:

$$A_i = \left[a_{ij} \right]_{1 \times m} \tag{15}$$

$$A_{ij} = \lambda \times Q_i + (1 - \lambda) \times P_i \tag{16}$$

Coefficient λ can be crisp value; and it can be any value from 0, 0.1, 0.2, ... , 1.0.

Step 7 Ranking of alternatives. The highest value of the alternative is the best ranked while the smallest value reflects the worst alternative.

4. Case study

4.1 Forming a Multi-Criteria Model

Three locations (Fig. 1) that are located in the Municipality of Derventa, of which one is connection between the town of Derventa and the town of Brod (Lužani), one that connects the town of Derventa and the town of Prnjavor (Lug), and one that passes by the town (Kninska Street), are evaluated based on a total of seven criteria presented in Table 1.

Fig. 1 Observed locations in the Municipality of Derventa

The first location is located in the Municipality of Derventa, and it represents the main road M14.1 The second location is an exit from the town of Derventa onto the M16.1 main road towards Prnjavor, while the third location is an exit from the town of Derventa onto the M14.1 towards Brod.

Table 1 Criteria in a multi-criteria model and their interpretation

Criterion	Criterion Description
C_1	Total number of traffic accidents with killed persons (quantitative data for last 6 years)
C_2	Total number of traffic accidents with seriously injured persons (quantitative data for last 6 years)
C_3	Total number of traffic accidents with slightly injured persons (quantitative data for last 6 years)
C_4	Total number of traffic accidents with property damage only (quantitative data for last 6 years)
C_5	Geometric design of road (qualitative data about curves, road width, upgrade, downgrade, etc.)
C_6	AADT (besides annual average daily traffic, quantitative data about the structure of traffic flow, car flow)
C_7	Traffic elements (qualitative data about condition of pavement, roadway, road markings (horizontal and vertical signalization)

Table 1 shows both the criteria and the detailed interpretation of their meaning. The criteria used in this study are traffic safety criteria, commonly used in Croatia and Serbia (Stević et al., 2018). Criteria number 1,2,3,4 and 6 represent quantitative data, while criteria number 5 and 7 represent qualitative data. When it comes to the number of traffic accidents, all data are obtained from Derventa Police Station. All data about number of accidents are shown in Fig. 2.

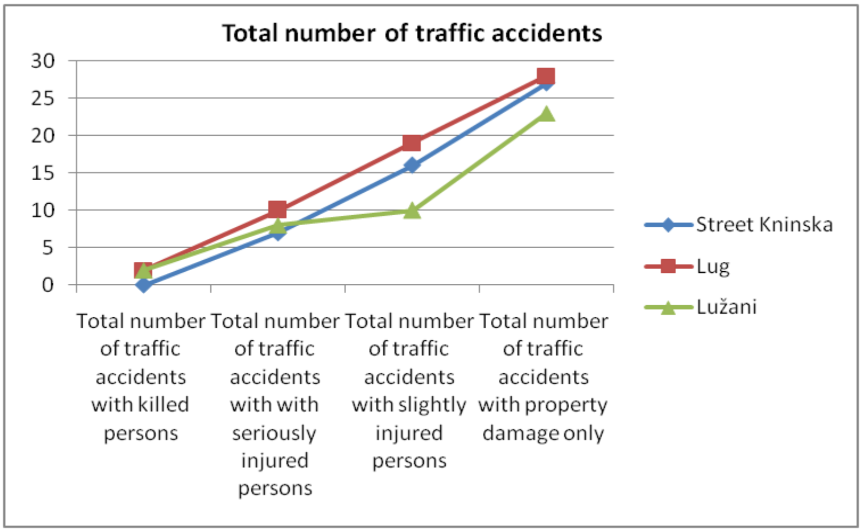

Fig. 2 Total number of traffic accidents for last 6 years

As the Fig. 2 shows, two traffic accidents with killed persons happened in location Lug and Lužani, while in the Kninska Street location no traffic accidents with killed persons happened. The highest number of accidents with seriously and slightly injured persons took place at the Lug location while the smallest number of traffic accidents with seriously injured persons happened on Kninska Street location. The smallest number of traffic accidents with property damage only took place at location No. 3, Lužani, while the highest number took place at the Lug location.

AADT data for three locations are shown in Fig. 3.

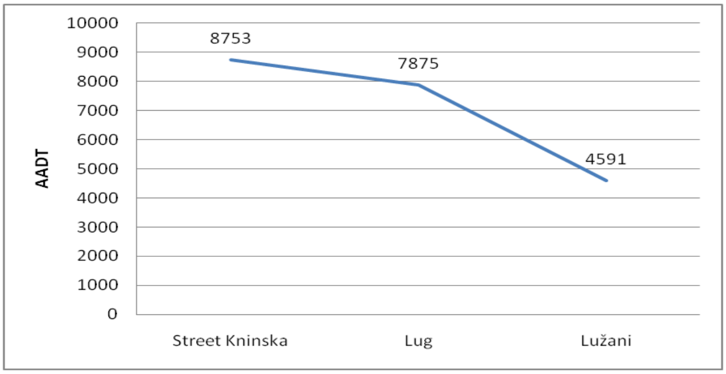

Fig. 3 AADT data for observed locations

Criterion number 6, AADT data about observed locations is based on the basis of data from the Roads of the Republic of Srpska's. AADT for first location is 8753 vehicle/day, for second location is 7875 vehicle/day, and for third location is 4591 vehicle/day.

4.2 Determining criteria weights the using FUCOM method

Step 1 Ranking the criteria based on their importance:

$$C_1 > C_2 > C_3 > C_4 > C_6 > C_7 = C_5$$

Table 2 The importance of criteria (FUCOM method)

Criterion	C_1	C_2	C_3	C_4	C_6	C_7	C_5
w_{cj}	1	1.8	2	2.5	2.6	3.4	3.4

Table 2 presents the importance of criteria used in the multi-criteria decision-making model, where we can see that the most important criterion is criterion 1, the total number of traffic accidents with killed persons. After that, the most important criteria are the total number of traffic accidents with seriously and slightly injured persons, separately. Then follows criterion 4 referring to the total number of traffic accidents with property damage only. The next criterion by importance is criterion 6, AADT. Criteria 5 and 7 have the same importance.

Step 2 Comparison of the ranked criteria is carried out and the comparative priority of the evaluation criteria is determined. Comparative priority of the evaluation criteria is obtained by equation (3):

$$\varphi_{C_1/C_2} = 1.8 \;\; \varphi_{C_2/C_3} = 1.11 \;\; \varphi_{C_3/C_4} = 1.25 \;\; \varphi_{C_4/C_6} = 1.04 \;\; \varphi_{C_6/C_7} = 1.31 \;\; \varphi_{C_7/C_5} = 1$$

Step 3 The final values of the weight coefficients are calculated by equation (4):

$$\frac{w_1}{w_3} = 2 \;\; \frac{w_2}{w_4} = 1.39 \;\; \frac{w_3}{w_6} = 1.30 \;\; \frac{w_4}{w_7} = 1.36 \;\; \frac{w_6}{w_5} = 1.31$$

Regarding the defined limitations, on the basis of expression (5), a finite model for determining the weight coefficients meeting the condition of maximum consistency can be defined.

$$\min \lambda$$
$$s.t. \begin{cases} \left|\frac{w_1}{w_2} - 1.8\right| \le \lambda; \left|\frac{w_2}{w_3} - 1.11\right| \le \lambda; \left|\frac{w_3}{w_4} - 1.25\right| \le \lambda; \left|\frac{w_4}{w_6} - 1.04\right| \le \lambda; \left|\frac{w_6}{w_7} - 1.31\right| \le \lambda; \left|\frac{w_7}{w_5} - 1\right| \le \lambda; \\ \left|\frac{w_1}{w_3} - 2\right| \le \lambda; \left|\frac{w_2}{w_4} - 1.39\right| \le \lambda; \left|\frac{w_3}{w_6} - 1.3\right| \le \lambda; \left|\frac{w_4}{w_7} - 1.36\right| \le \lambda; \left|\frac{w_6}{w_5} - 1.31\right| \le \lambda; \\ \sum_{j=1}^{m} w_j = 1, w_j \ge 0, \forall_j \end{cases}$$

Final results for weight coefficients were obtained using the LINGO 17 program, and it follows:

$$w_1 = 0.292 \;\; w_2 = 0.162 \;\; w_3 = 0.146 \;\; w_4 = 0.117 \;\; w_5 = 0.086 \;\; w_6 = 0.112$$
$$w_7 = 0.086$$

After the completed calculation, it can be concluded that the most important criterion is the total number of traffic accidents with killed persons, whose weight coefficient is $w_1 = 0.292$. Deviation from full consistency (DFC) was obtained as 0.00.

4.3 Ranking dangerous sections road using WASPAS method

Step 1 Formatting of initial decision matrix (*X*).

The data shown in Figs. 2 and 3 are used to form the initial decision matrix (Table 4), in the first step of the WASPAS method. All criteria have been evaluated by using Linguistic scale, presented in Table 3. All criteria were evaluated by obtained data, depending on their type, max/min type.

Table 3 Linguistic scale for evaluating qualitative criteria (Stević et al., 2017)

Linguistic scale	For Criteria Max Type	For Criteria Min Type
Very poor (VP)	1	9
Poor (P)	3	7
Medium (M)	5	5
Good (G)	7	3
Very good (VG)	9	1

Criterion 5 (geometric design of road in location number one and location number three) was evaluated by linguistic scale, and it is poor (P). Geometric design of road in location number two was evaluated by previous scale, and it is good (G). Kninska Street, the first location, is the main road M14.1.The beginning of the hall is a crossroad, at an angle of 90 degrees. Most of the hall is a straight line, along which there are four mild curves, and one bridge. The main road is characterized by a large number of percussion holes, damaged carriageway and very poor roadblock status, making it the lowest scoring on the scale. The second location, Lug, represents the M16.1 main road, from Derventa towards Prnjavor. This layout of the main road M16.1 is a route along which there are no curves. The condition of the carriageway is rated as good, with curbside and protective equipment alongside the road. The location of Lužani is rated at grade 3 because of the fact that on this section of main road M14.1 from Derventa towards Brod, there is a major damage on road. Except for that, the grade "poor" was given because there are two sharp curves on this part of the road, one of which is steep.

Criterion number seven, traffic elements, was evaluated by linguistic scale, as poor (P) for location one, and medium (M) for location number two and three. Location number one is rated poor (P) because of no placed vertical signaling at all the necessary locations along the layout. Edge lines as well as dividing lines in certain places are not sufficiently noticeable, especially in night conditions. Location number two and three are rated as medium (M) because there are adequate vertical signaling on these sections of the road. All traffic signs are in a good condition. Horizontal signaling is well known, visible in day and night conditions.

Table 4 Initial decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
L_1	1	5	5	7	3	5	3
L_2	5	7	7	7	7	5	5
L_3	5	5	3	5	3	7	5
	min	min	min	min	max	min	max
	1	5	3	5	7	5	5

Step 2 Normalization of the initial matrix using Eqs. (7), (8). Normalization of the initial matrix (Table 5) has been done according to the type of criteria. If it is maximum, we use equation (7), and if it is minimum we use equation (8). The first example represents the minimum criteria, and the second example represents the maximum criteria.

$$n_{21} = \frac{1}{5} = 0.200$$

$$n_{15} = \frac{3}{7} = 0.429$$

Table 5 Normalization of the initial decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
L_1	1.000	1.000	0.600	0.714	0.429	1.000	0.600
L_2	0.200	0.714	0.429	0.714	1.000	1.000	1.000
L_3	0.200	1.000	1.000	1.000	0.429	0.714	1.000

Step 3 Weighting of the normalized matrix is done in such a way that the previous (normalized) matrix is multiplied by the weight coefficients, by using equation (10). Table 6 represents the normalized matrix with weight coefficients which is used to form weighted normalized matrix.

Table 6 Normalized initial matrix with weight coefficients

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
L_1	1.000	1.000	0.600	0.714	0.429	1.000	0.600
L_2	0.200	0.714	0.429	0.714	1.000	1.000	1.000
L_3	0.200	1.000	1.000	1.000	0.429	0.714	1.000
w_{cj}	0.292	0.162	0.146	0.117	0.086	0.112	0.086

$$V_{11} = 0.292 \times 1.000 = 0.292$$

After using equation (10), like in the previous example, the normalized initial matrix is weighted (Table 7).

Table 7 Weighted normalized matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
L_1	0.292	0.162	0.088	0.084	0.037	0.112	0.052
L_2	0.058	0.116	0.063	0.084	0.086	0.112	0.086
L_3	0.058	0.162	0.146	0.117	0.037	0.080	0.086

Step 4 Summarizing all obtained values of the alternatives by using equation (11), (12) (summation in rows):

$$S_1 = 0.292 + 0.162 + 0.088 + 0.084 + 0.037 + 0.112 + 0.052 = 0.826$$

This step implies that every row in Table 7 must be summarized. By summing up every row, we form the next table, Table 8.

Table 8 Summation in rows

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	S_i
L_1	0.292	0.162	0.088	0.084	0.037	0.112	0.052	0.826
L_2	0.058	0.116	0.063	0.084	0.086	0.112	0.086	0.604
L_3	0.058	0.162	0.146	0.117	0.037	0.080	0.086	0.686

Step 5 Determination of the weighted product model by using Eqs. (13), (14):

$$P_1 = 1.000^{0,292} \times 1.000^{0,162} \times 0.600^{0,146} \times 0.714^{0,117} \times 0.429^{0,086} \times 1.000^{0,112} \times 0.600^{0,086} = 0.794$$

Weighted product model (Table 9) is formed by using Eqs. (13) and (14) as in the previous example. The weighted product model is used to determinate the relative values of the alternatives.

Table 9 Weighted product model

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	P_i
L_1	1.000	1.000	0.928	0.961	0.930	1.000	0.957	0.794
L_2	0.625	0.947	0.884	0.961	1.000	1.000	1.000	0.503
L_3	0.625	1.000	1.000	1.000	0.930	0.963	1.000	0.560

Step 6 Determination of the relative values of alternative A_i:

$$A_1 = 0.5 \times 0.828 + (1 - 0.5) \times 0.794 = 0.810$$

$$A_2 = 0.5 \times 0.604 + (1 - 0.5) \times 0.503 = 0.554$$

$$A_3 = 0.5 \times 0.686 + (1 - 0.5) \times 0.560 = 0.623$$

Step 7 Ranking of alternatives. The final step of the WASPAS method means ranking of alternatives by their values. By using the FUCOM method for determining the weight coefficients and the WASPAS method for ranking the locations, we have obtained that the best alternative is Location number 1 (Kninska Street). After location 1, the best ranked alternative is location 3; that is why location 2 represents the most dangerous location of the road in terms of traffic safety. All data about values of the alternatives is shown in Table 10.

Table 10 Ranking of alternatives

	Q_i	P_i	A_i
L_1	**0.826**	**0.794**	**0.810**
L_2	0.604	0.503	0.554
L_3	0.686	0.560	0.623

$$L_1 > L_3 > L_2$$

4.4 Sensitivity analysis

The results of the multi-criteria models can significantly be influenced by the values of degree of consistency λ. The value of λ goes from 0, 0.1, 0.2, ..., 1. That is why the analysis of the influence of values of λ on the results of the research is done. Therefore, in this part of the paper the sensitivity analysis of the ranks of alternatives to changes in value of λ is carried out. The sensitivity analysis is performed through ten situations. In every situation, values of λ is different, starting from 0,0.1,0.2, ...,1. The obtained ranges are shown in Fig. 4.

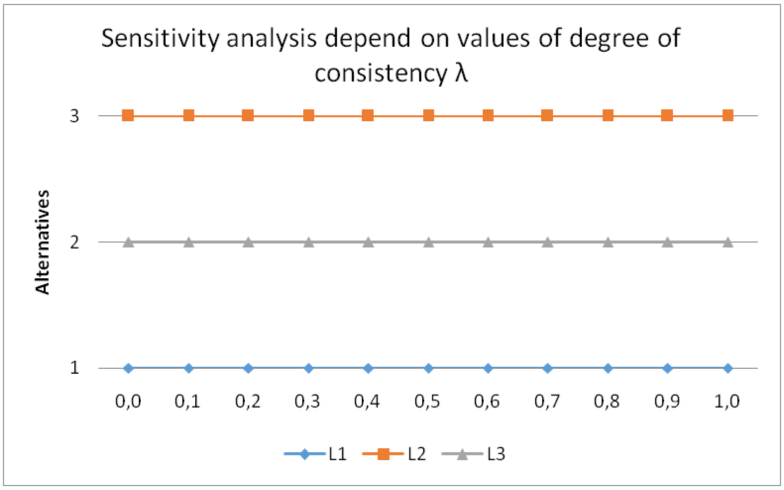

Fig. 4 Sensitivity analysis

After sensitivity analysis is done, the obtained results show that there is no difference in ranking dangerous sections of the road in the territory of the Municipality of Derventa. For all changes value of λ the ranking results are the same:

$$L_1 > L_3 > L_2$$

Location number 1 is the best ranked alternative. Location number 2 is the most dangerous sections of the road, and it is ranked as the third alternative.

5. Conclusion

This research study presents the use of the multi-criteria FUCOM-WASPAS model for ranking dangerous sections of the road in the Municipality of Derventa. The FUCOM-WASPAS model used in the study encompasses seven traffic safety criteria that are evaluated by the Linguistic scale presented in the paper. By applying the FUCOM-WASPAS model three different sections of the road were ranked. The results obtained were verified through the sensitivity analysis carried out on the basis of different values of degree of consistency λ. In every case, location Kninska Street was best ranked alternative, while the location Lug is ranked as the most dangerous section of the road, from all observed locations at the Municipality of Derventa.

In order to manage the safety of traffic, it is necessary to know the existing situation, which can include ranking dangerous sections of the road. The process of ranking the road sections would help us determine the locations having the priorities when it comes to making decisions about improvements in traffic safety. When we find out which section is the most dangerous section of the road, it is easier to take the management and every other measure to improve safety of traffic starting from the most dangerous section. Also, ranking of the road sections gives data to the traffic participants that would serve them as the basis for choosing a safer way to their finish line.

In addition, the model presented in this paper introduces new methodological principles for evaluating the dangerous sections of the road, which at the same time contributes to the improvement of theoretical basis of multi-criteria decision making in general. Future research related to this paper may imply the improvement of the proposed methodology by defining universal criteria for ranking dangerous sections of the road and the possibility of developing new approaches in the area of multi-criteria decision-making.

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