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Multi-Criteria Decision-Making Model for Evaluating Safety of Road Sections

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Abstract: Road capacity utilization is causally connected with an appropriate level of efficiency and an optimal level of traffic safety. Therefore, in this paper, it is considered the issue of maximum utilization of road capacity through the maximization of the input parameter AADT (Annual Average Daily Traffic), and the minimization of output parameters related to the categories of traffic accidents. It was defined six main road sections, which were evaluated based on seven techno-operational criteria using an integrated Multi-criteria decision-making (MCDM) model. The data refer to buses as a vehicle category. The Improved Fuzzy Step-Wise Weight Assessment Ratio Analysis (IMF SWARA) method was chosen to determine the weights of criteria, while the road sections were ranked using the Evaluation based on distance from average solution (EDAS). In addition, in one of the stages of applying the model when it comes to AADT, the Bonferroni operator (BFO) is used. The results show that the highest level of safety refers to a main road section with the following characteristics: average AADT, minimal deviation from the speed limit, an ascent of 7% and the lowest number of traffic accidents by all categories. In the paper, it was performed a multi-phase sensitivity analysis in order to identify possible differences in results when determining new circumstances.

Keywords: Road sections; IMF SWARA method; Traffic safety; AADT; EDAS

1. Introduction

Risk assessment in road transportation is mainly based on strategic risk assessment. Strategic risk refers to long-term decisions made by institutions that control traffic safety in the areas analyzed. The main focus of researchers is usually related to the causes and consequences of road traffic accidents and the reliability of appropriate infrastructure to reduce risk [1]. The efficiency of a traffic system is also associated with the prediction of traffic flows (AADT), and thus the overruns regarding the daily, weekly, monthly, quarterly and annual prediction. By introducing exogenous factors and dummy variables in the prediction, ensembles with different review periods were created [2]. At the same time, the conducted research on the modeling of road, socioeconomic and land characteristics on AADT, using the method of least squares and geographically weighted regression on ten spatially distributed districts, shows that road density, land use and AADT on the nearest non-local road have a significant impact on the AADT of the local road [3]. Additionally, traffic monitoring programs can be adapted for the needs of developing spatial models. The output of these models can be used to assess the impact of land use on active travel rates and, as an input, to assess exposure to the negative effects of traffic safety [4].

By researching the attitudes of a sample of 331 bus drivers over a period of six months, it was shown that the external environment and company management, according to the structural equation, reveal the risky behavior of bus drivers directly and indirectly [5]. Such indicators can provide an empirical basis for road traffic safety interventions. Also, based on a survey of 107 bus drivers in Iran, it was developed a logistic regression model indicating a number of factors (driving older buses, inexperienced drivers, smokers and night drivers) with a higher probability of being involved in traffic accidents [6]. Based on limited research on a driving simulator about the impact of stopping a school bus in relation to surrounding drivers, it was determined a different traffic law awareness status, traffic volume status and initial location status of the bus. The results showed that after the promotion of laws and regulations, the speed of driving is significantly lower, and the number of people complying with the regulations has increased, which positively affects the potential risk [7].

Based on research on traffic infrastructure elements for buses, it was determined that the risk of a traffic accident near bus stops is higher because bus stops are near intersections and side roads, where an accident is more likely to occur, and not because of the design of the elements of traffic infrastructure [8].

The aim of this paper is to create an adequate integrated IMF SWARA-EDAS model based on the Bonferroni operator for the ranking of road infrastructure sections for buses as a category of vehicles. This kind of model has just been presented for the first time in the literature, which gives special importance and novelty to this paper as well.

After the introduction, the paper is created through the following sections. Section 2 provides the algorithms of the IMF SWARA method, the EDAS method and the Bonferroni operator which was used to average the AADT for a period of five years. Section 3 presents the definition of input data, their averaging, the formation of an initial decision matrix, and the application of the defined MCDM model in order to obtain results that are also given in this section of the paper. In Section 4, verification was performed by applying the following tests: simulation of new criterion weights through 70 scenarios, testing the influence of matrix size and comparative analysis with other five MCDM methods. The paper ends with concluding considerations and guidelines for the continuation of the research.

2. Methodology

Further in the paper, it is presented the applied methodology which consists of IMF SWARA, EDAS and Bonferroni operator, the steps of which are given in detail.

2.1 IMF SWARA Method

Vrtagić et al. [9] developed the Improved fuzzy SWARA method and it includes the following steps [10]:

Step 1: Defining all the criteria used for decision-making, and sorting them in descending order.

Step 2: Using the previously determined ranking, it is identified a relatively smaller importance of a criterion (criterion *Cj*) in relation to the previous one (*Cj−1*). This relation, i.e. comparative importance of an average value, is denoted by $\overline{s_j}$. An appropriate TFN scale that facilitates accurate and high-quality determining the importance of criteria by IMF SWARA is given in Table 1.

Table 1. TFN scale for evaluating the criteria

Linguistic Variable	Abbreviation	TFN Scale		
Absolutely less significant	ALS	1	1	1
Dominantly less significant	DLS	1/2	2/3	1
Much less significant	MLS	2/5	1/2	2/3
Really less significant	RLS	1/3	2/5	1/2
Less significant	LS	2/7	1/3	2/5
Moderately less significant	MDLS	1/4	2/7	1/3
Weakly less significant	WLS	2/9	1/4	2/7
Equally significant	ES	0	0	0

Step 3: Determination of the fuzzy coefficient $\overline{k_j}$ (1):

$$\overline{k_j} = \begin{cases} \bar{1} & j = 1 \\ \overline{s_j} \oplus \bar{1} & j > 1 \end{cases} \tag{1}$$

Comparative importance of the average value is denoted by $\overline{s_j}$.

Step 4: Determination of the calculated weights $\overline{q_j}$ (2):

$$\overline{q_j} = \begin{cases} \bar{1} & j = 1 \\ \dfrac{\overline{q_{j-1}}}{\overline{k_j}} & j > 1 \end{cases} \tag{2}$$

$\overline{k_j}$ is a fuzzy coefficient from the previous step.

Step 5: Calculation of the fuzzy weight coefficients by applying Eq. (3):

$$\overline{w_j} = \frac{\overline{q_j}}{\sum_{j=1}^{m} \overline{q_j}} \tag{3}$$

where, w_j represents the fuzzy relative weight of the criteria j, and m represents the total number of criteria.

2.2 Bonferroni Operator

The Bonferroni and Perez-Arellano et al. operator [11, 12] was applied in this case in order to calculate the average value of AADT for a period of five years.

$$a_{ij} = \left(\frac{1}{e(e-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{e} a_i^{mp} \otimes a_j^{mq} \right)^{\frac{1}{p+q}} \tag{4}$$

where, e is a number of years of the AADT, and $p, q \geq 0$, is a group of positive numbers.

2.3 EDAS Method

This method was created in 2015 [13]. When solving problems using the EDAS method, the following steps are applied:

Step 1. Defining an initial table in which the characteristics of alternatives according to criteria are presented in a classic way.

Step 2. Calculation of the average value of all criteria:

$$AV_j = \frac{\sum_{i=1}^{n} x_{ij}}{n} \tag{5}$$

x_{ij} denotes the value of i alternative in relation to j criteria.

Step 3. Calculation of the positive distance from the average value (PDA) and the negative distance from the average value (NDA), according to the types of criteria:

if B:

$$PDA_{ij} = \frac{\max\left(0, \left(x_{ij} - av_j\right)\right)}{av_j} \tag{6}$$

In case the criterion is C:

$$PDA_{ij} = \frac{\max\left(0, \left(av_j - x_{ij}\right)\right)}{av_j} \tag{7}$$

if B:

$$NDA_{ij} = \frac{\max\left(0, \left(av_j - x_{ij}\right)\right)}{av_j} \tag{8}$$

In case the criterion is C:

$$NDA_{ij} = \frac{\max\left(0,\left(x_{ij} - av_j\right)\right)}{av_j} \tag{9}$$

Step 4. Determining the weighted value of the sum of PDA and NDA for each alternative:

$$\begin{aligned} SP_i &= \sum_{i=1}^{m} w_j \times pda_{ij} \\ SN_i &= \sum_{i=1}^{m} w_j \times nda_{ij} \end{aligned} \tag{10}$$

w_j is the value of criterion importance.
Step 5. Normalizing SP and SN values for all alternatives:

$$NSP_i = \frac{SP_i}{\max SP_i} \tag{11}$$

$$NSN_i = 1 - \frac{SN_i}{\max SN_i} \tag{12}$$

Step 6. Calculation of the average estimate for all alternatives:

$$AS_i = \frac{NSP_i + SN_i}{2}, \quad 0 \le AS_i \le 1 \tag{13}$$

Step 7. Ranking the alternatives according to descending assessment values (AS).

3. Results

This section shows the results of applying the previously developed model with the analysis of influential parameters, characteristics of main road sections (Table 2), as well as the setting of a multi-criteria model, the results of determining criterion weights and the ranking of considered sections.

Table 2. Main characteristics of the observed road sections

	Road sections	Section code	Section length km	Ascent/descent at 1000 m in %	Speed limit (km/h)	Speed deviation from the speed limit
A1	Vrhovi-Šešlije I	M-I-103	14.073	-5.00%	80	3.000
A2	Vrhovi-Šešlije II	M-I-103	14.073	-1.92%	80	4.000
A3	Rudanka-Doboj	M-I-105	7.405	-0.017%	60	1.000
A4	Šepak-Karakaj 3	M-I-115	20.95	+1.00%	80	0.100
A5	Donje Caparde-Karakaj 1	M-I-110	15.35	+3.00%	80	0.100
A6	Border (RS/FBIH)-Donje Caparede	M-I-110	3.14	+7.00%	80	0.100

Based on the analysis carried out on six sections of main roads in Bosnia and Herzegovina, Table 2 provides the values of speed limits, as well as deviations from the speed limits for buses. Different lengths of sections combined with values of longitudinal gradients (ascent/descent) were taken by random sampling in empirically obtaining values of deviations from speed limits.

3.1 Criteria Defined

In this paper, it is defined a set of seven criteria, which are marked as follows: C1 - ascent/descent at 1000 m in %, C2 - deviation from the speed limit, C3 - AADT, C4 - traffic accidents with fatalities (TA-F), C5 - TA with seriously injured (TA-S. inj.), C6 - TA with slightly injured (TA-S. inj.) and C7 – TA with material damage (TA-MD).

Figure 1 shows the AADT for a period of five years. The last available data relating to the interval 2013-2017 were used. The average values of AADT using the Bonferroni operator are shown, too.

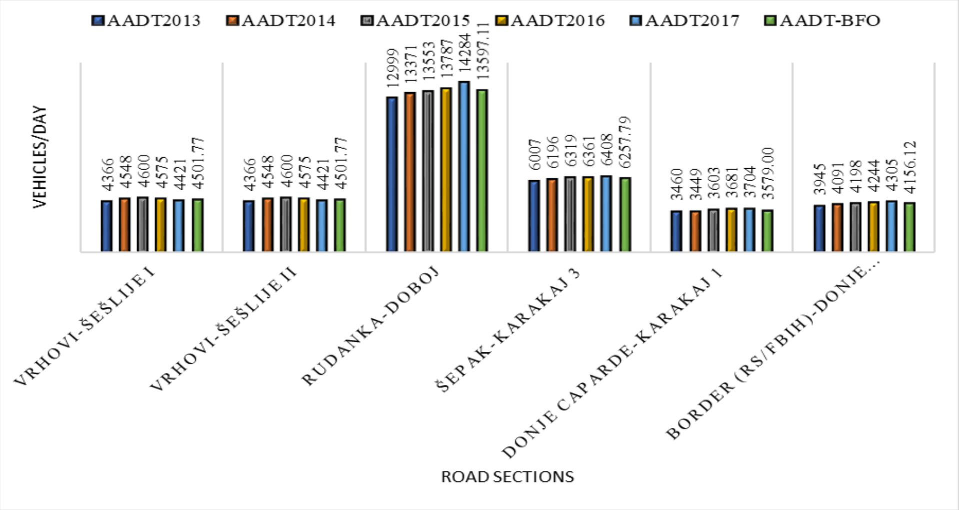

Figure 1. AADT for a period of five years

By analyzing the third criterion C3, the average values of AADT in the five-year period are approximate and do not exceed the value of 6500 [veh/day], which is not the case on the section Rudanka-Doboj, where there is a significant deviation of AADT from the values on other sections.

The available data for traffic accidents, taking into account all categories, are in the interval from 2015 to 2019 and are shown in Figure 2. For their averaging, the geometric mean was applied and that value was further included in the MCDM model.

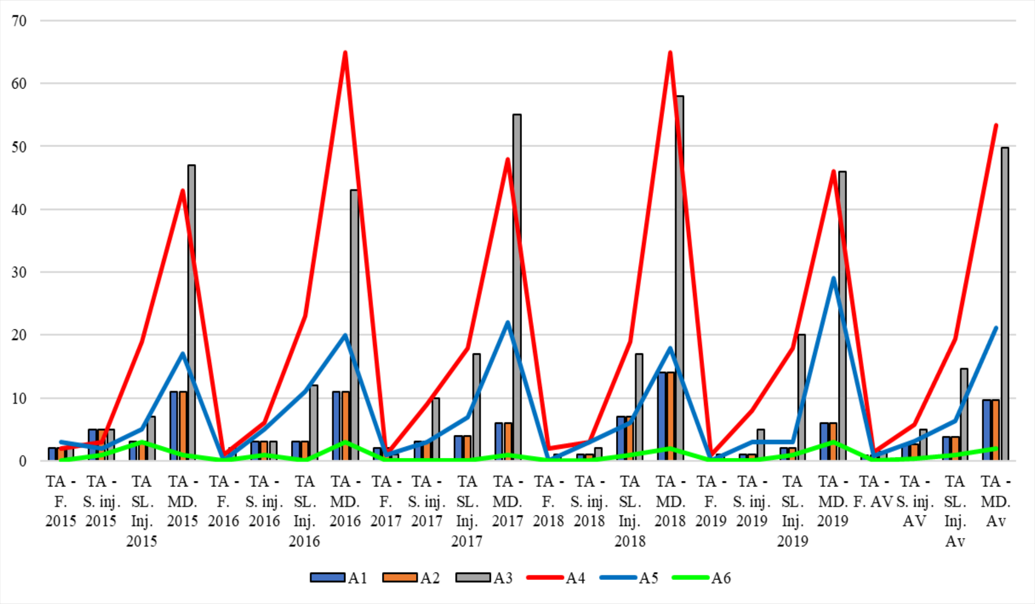

Figure 2. Number of traffic accidents classified by categories

In Figure 2, showing the number of accidents from 2015 to 2019, the highest number of traffic accidents is with material damage, and the lowest with fatalities, so finding the arithmetic mean of the number of accidents on given sections cannot be taken subjectively. That is why the given values are classified according to the severity of consequences and according to the years of observation.

3.2 Determining the Weights of the Criteria Using the IMF SWARA Method

Based on defining a list of criteria according to their importance, determining comparative values using the scale mentioned above, and applying Eqns. (1)-(3), it was obtained the weight values of the criteria, shown in Table 3.

Table 3. Calculation of criterion weights using the IMF SWARA method

	Sj			Kj			qj			wj			DF
C4				1.000	1.000	1.000	1.000	1.000	1.000	0.218	0.228	0.240	0.228
C5	1/4	2/7	1/3	1.250	1.286	1.333	0.750	0.778	0.800	0.164	0.177	0.192	0.177
C2	0	0	0	1.000	1.000	1.000	0.750	0.778	0.800	0.164	0.177	0.192	0.177
C3	2/9	1/4	2/7	1.222	1.250	1.286	0.583	0.622	0.655	0.127	0.142	0.157	0.142
C1	2/9	1/4	2/7	1.222	1.250	1.286	0.454	0.498	0.536	0.099	0.113	0.129	0.113
C6	2/9	1/4	2/7	1.222	1.250	1.286	0.353	0.398	0.438	0.077	0.091	0.105	0.091
C7	2/9	1/4	2/7	1.222	1.250	1.286	0.274	0.319	0.359	0.060	0.073	0.086	0.073
						SUM	4.164	4.392	4.587				

As can be concluded from the obtained results, the greatest importance is given to TAs with fatalities, which is expected considering the set goal related to determining the level of safety of the considered sections. The second and third criterion according to importance refer to C5 – TA-Ser. inj. and C2 - deviation from the permissible speed limit, which have equal values. The least significant criterion in the given circumstances is C7 – TA-MD. The obtained weights are further implemented in the continuation of the MCDM model.

3.3 Ranking of Road Sections Using the EDAS Method

Based on the previously collected and processed data, it was formed an initial decision matrix (Table 4), which for the first two criteria represents the quantified values of decision-makers' assessment, and the other criteria represent the average values based on the previous explanation.

Table 4. Initial decision matrix using quantitative and qualitative data

	C1	C2	C3	C4	C5	C6	C7
A1	7	3	4484.25	0.8	2.6	3.8	9.6
A2	3	4	4484.25	0.8	2.6	3.8	9.6
A3	1	1	13293.31	1.4	5	14.6	49.8
A4	2	0.1	6148.48	1.4	5.8	19.4	53.4
A5	4	0.1	3503.25	0.8	3.2	6.4	21.2
A6	5	0.1	4053.14	0.00	0.4	1	2
	MIN	MIN	MAX	MIN	MIN	MIN	MIN

Applying the methodology of the EDAS method, i.e. Eqns. (5)-(12), taking into account the weighting procedure with the weights obtained by applying the IMF SWARA method, the final results are shown in Table 5.

Table 5. Results obtained by applying the IMF SWARA-EDAS model

	SPI	NSI	NSPI	NSNI	ASi	Rank
A1	0.054	0.346	0.098	0.067	0.083	5
A2	0.074	0.371	0.136	0.000	0.068	6
A3	0.304	0.234	0.555	0.368	0.462	3
A4	0.220	0.278	0.401	0.251	0.326	4
A5	0.186	0.069	0.339	0.813	0.576	2
A6	0.548	0.087	1.000	0.765	0.883	1

The values obtained using the IMF SWARA-EDAS model rank the Border (RS/FBIH)-Donje Caparede section with the highest, and the Vrhovi-Šešlije II section, with a descent of -1.92%, with the lowest potential risk, according to the criteria specified. The section with the highest AADT value is rated with an average rank, according to the specified methodology of the ranking model.

4. Discussion with Sensitivity Analysis

This section consists of verification tests. First, a simulation of criterion weights was carried out through 70 scenarios (Figure 3) in order to determine possible deviations from the originally obtained results, while taking into account new circumstances related to the importance of input indicators.

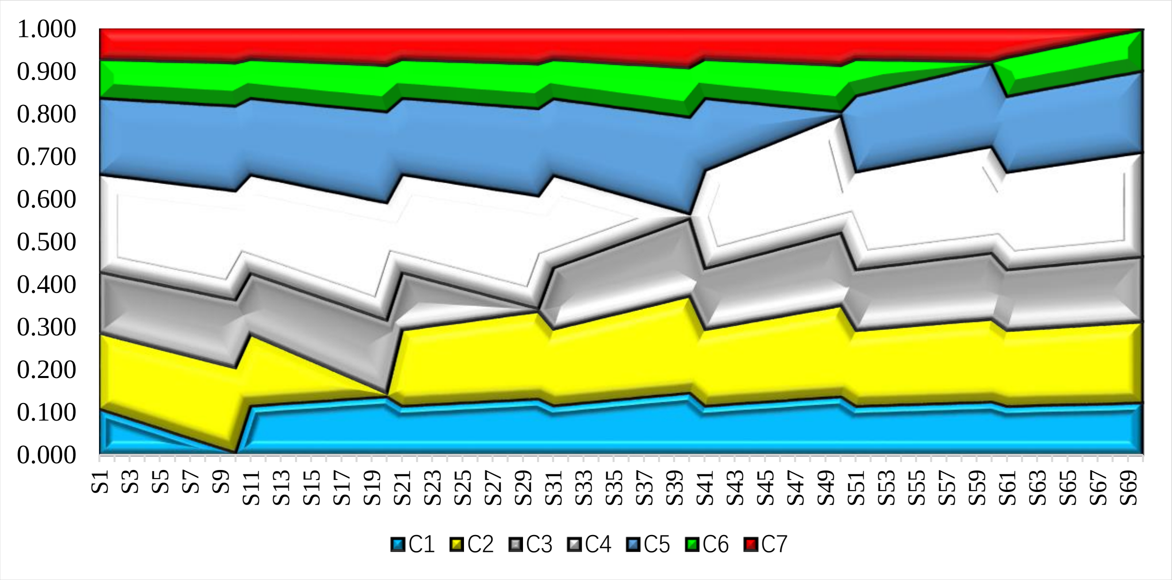

Figure 3. Criterion values through 70 simulated scenarios

The simulation through 70 scenarios was performed by reducing the weights of each criterion in a range of 5-95%, while the values of the other criteria were proportionally increased depending on each scenario individually. Based on these values, 70 models were reproduced again, and their results are presented in Figure 4.

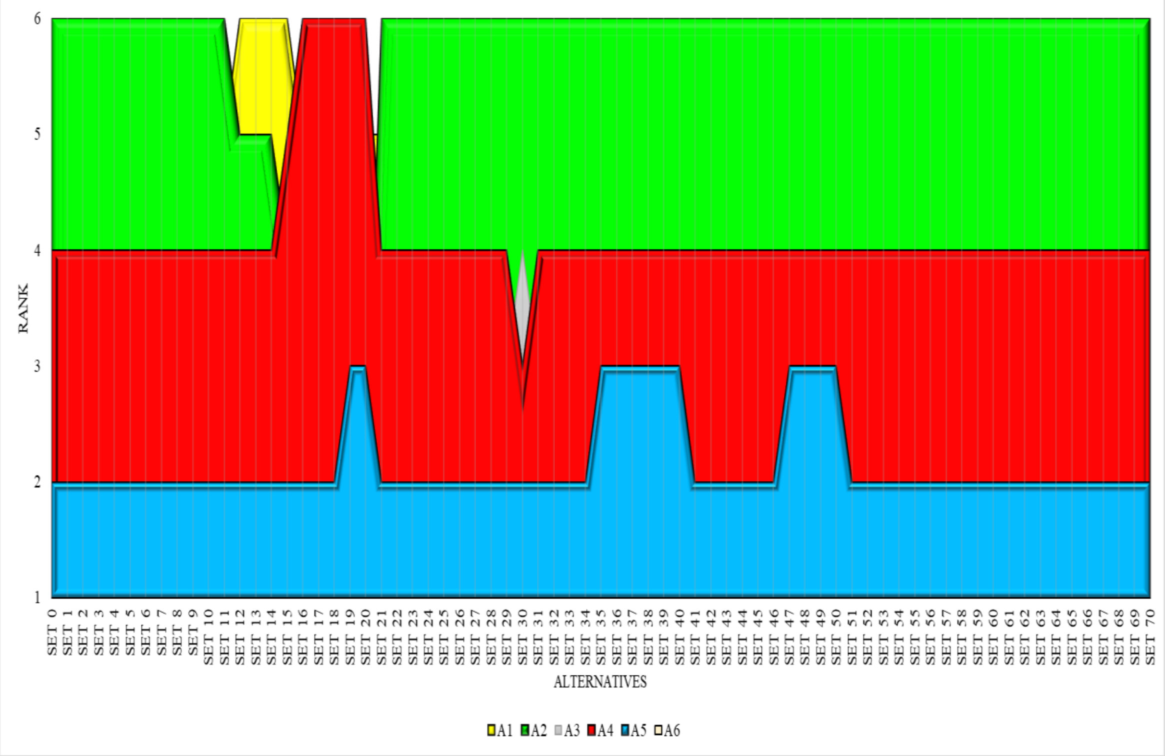

Figure 4. Results of sensitivity analysis through simulated criterion weights

In Figure 4, it can be seen that in certain scenarios there is a change in the ranking of particular road sections, with the fact that the best ranked section does not change the first position regardless of the importance of the criteria, which implies that it has the best performance by far. A1 changes its position in scenarios S12-S15, while it keeps its original position in others. The situation with A2 is interesting since it is mostly in the last place, but in S19 and S20 it reaches the second position, which means that the second criterion, deviation from the speed limit, plays an important role, more precisely, when its value is reduced to a minimum, A2 improves its ranking. This is logical, given that A2 has the worst value according to the second criterion. Other alternatives change their rank in certain scenarios, but not too much. The next verification test involves analyzing the impact of the initial matrix size, the results of which are shown in Figure 5. This test implies that in each scenario the worst alternative is eliminated and the model is reproduced again.

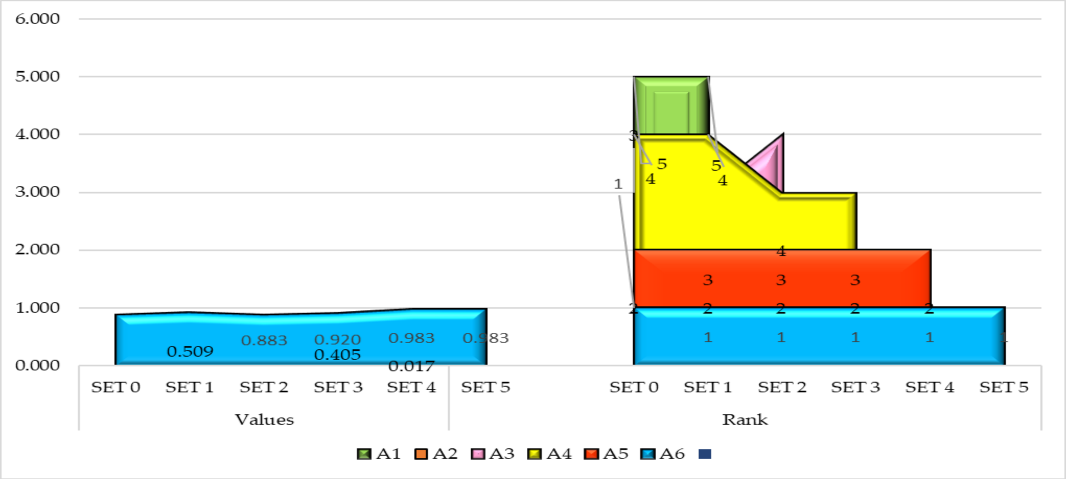

Figure 5. Results of the analysis of the influence of MCDM matrix size

On the left side of Figure 5, the values of the alternatives are shown, and on the right, the ranks for each new model, which consists of one alternative less compared to the previous model. The only change that occurs in this analysis is in the second scenario, when the total number of alternatives is reduced to four. Then A3 takes the fourth instead of the third position, i.e. exchange the position with A4.

In the last test, it was performed a comparative analysis with MARCOS [14], CRADIS [15, 16], WASPAS [17], ARAS [18], SAW [19].

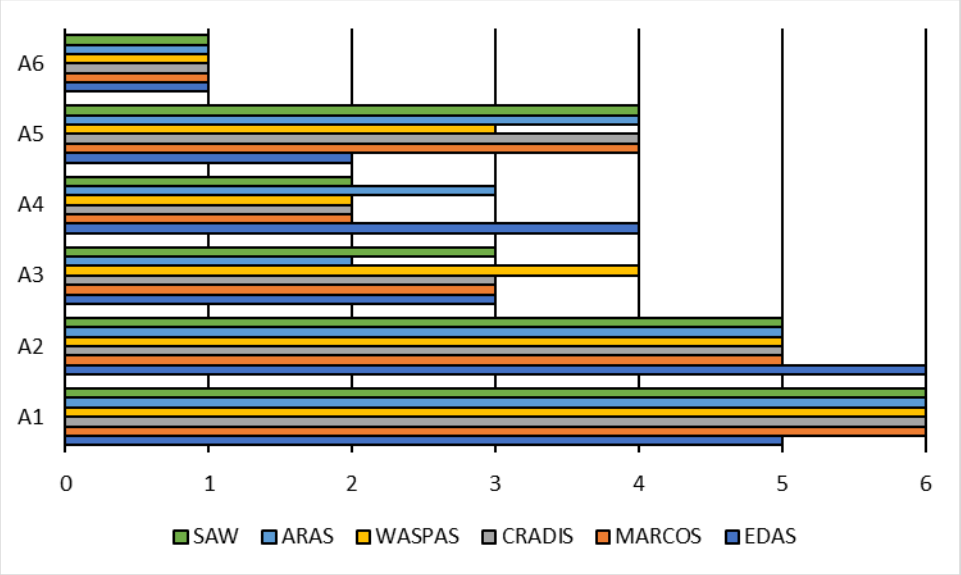

Figure 6. Results of comparative analysis

The comparative analysis (Figure 6) shows that there are certain deviations in the ranks, but which are generally highly correlated with the original model.

5. Conclusions

The paper analyzes the risk assessment for the movement of buses on the given road sections, which are included as potential alternatives. By applying MCDM, it was analyzed seven criteria, and each of them influenced the potential definition of reference values. Section A6 was assessed as the riskiest section, and section A2 as the least risky for bus movement, according to pre-defined criteria.

It is shown that the section Rudanka-Doboj, regardless of AADT, does not represent the best nor the worst ranked section from the aspect of traffic risk, according to the mentioned criteria for bus movement. By sensitivity analysis, testing was carried out through 70 scenarios. By applying different sensitivity analyses through simulated criterion weights, it was determined that the ranking would be variable, in terms of certain sections for the movement of BUSes.

In guidelines for further research, it is especially necessary to note that with an increase in the number of sections, it can be determined potential groups of risky sections for the movement of buses, which is especially important for reducing traffic risk in public mass movement of passengers.

Author Contributions

"Conceptualization, Ž.S. and M.S.; methodology, Ž.S.; validation, M.S., E.S. and B.B.; formal analysis, M.S.; investigation, B.B.; data curation, Ž.S.; writing—original draft preparation and M.S, Ž.S.; writing—review and editing, M.S. and E.S; supervision, E.S.; project administration, B.B. All authors have read and agreed to the published version of the manuscript."

Data Availability

The data supporting our research results are included within the article or supplementary material.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] A. Tubis, "Risk assessment in road transport–strategic and business approach," *J. KONBiN*, vol. 45, no. 1, pp. 305-324, 2018. https://doi.org/10.2478/jok-2018-0016.

[2] L. Wang, Y. Wang, L. Shi, and H. Xu, "Analysis of risky driving behaviors among bus drivers in China: The role of enterprise management, external environment and attitudes towards traffic safety," *Accident Analysis & Prevention*, vol. 168, Article ID: 106589, 2022. https://doi.org/10.1016/j.aap.2022.106589.

[3] M. M. Besharati and A. Tavakoli Kashani, "Factors contributing to intercity commercial bus drivers' crash involvement risk," *Arch. Environ. Occup. H.*, vol. 73, no. 4, pp. 243-250, 2017. https://doi.org/10.1080/19338244.2017.1306478.

[4] N. T. Ratrout, U. Gazder, and E. S. M. El-Alfy, "Effects of using average annual daily traffic (AADT) with exogenous factors to predict daily traffic," *Procedia Comput. Sci.*, vol. 32, pp. 325-330, 2014. https://doi.org/10.1016/j.procs.2014.05.431.

[5] S. Hankey, T. Lu, A. Mondschein, and R. Buehler, "Spatial models of active travel in small communities: Merging the goals of traffic monitoring and direct-demand modeling," *J. Transp. Health*, vol. 7, pp. 149-159, 2017. https://doi.org/10.1016/j.jth.2017.08.009.

[6] Y. Chen, Y. Guo, X. Gu, Y. Zhou, Y. Tong, and B. Cao, "Investigating the effect of school bus stopping process on driver behavior of surrounding vehicles based on a driving simulator experiment," *Int. J. Environ. Res. Public Health*, vol. 18, no. 23, Article ID: 12538, 2021. https://doi.org/10.3390/ijerph182312538.

[7] R. O. Phillips, O. H. Hagen, and S. H. Berge, "Bus stop design and traffic safety: An explorative analysis," *Accident Analysis & Prevention*, vol. 153, Article ID: 105917, 2021. https://doi.org/10.1016/j.aap.2020.105917.

[8] S. S. Pulugurtha and S. Mathew, "Modeling AADT on local functionally classified roads using land use, road density, and nearest nonlocal road data," *J Transp. Geogr.*, vol. 93, Article ID: 103071, 2021. https://doi.org/10.1016/j.jtrangeo.2021.103071.

[9] S. Vrtagić, E. Softić, M. Subotić, Ž. Stević, M. Dordevic, and M. Ponjavic, "Ranking road sections based on MCDM model: New improved fuzzy SWARA (IMF SWARA)," *Axioms*, vol. 10, no. 2, pp. 92-92, 2021. https://doi.org/10.3390/axioms10020092.

[10] N. Vojinović, Ž. Stević, and I. Tanackov, "A novel IMF SWARA-FDWGA-PESTEL analysis for assessment of healthcare system," *Oper. Res. Eng. Sci. T. Appl.*, vol. 5, no. 1, pp. 139-151, 2022. https://doi.org/10.31181/oresta070422211v.

[11] C. Bonferroni, "Sulle medie multiple di potenze," *Bollettino dell'Unione Matematica Italiana*, vol. 5, no. 3-4, pp. 267-270, 1950.

[12] L. A. Perez-Arellano, F. Blanco-Mesa, E. Leon-Castro, and V. Alfaro-Garcia, “Bonferroni prioritized aggregation operators applied to government transparency,” *Mathematics-Basel*, vol. 9, no. 1, Article ID: 24, 2020. https://doi.org/10.3390/math9010024.

[13] M. Keshavarz Ghorabaee, E. K. Zavadskas, L. Olfat, and Z. Turskis, “Multi-criteria inventory classification using a new method of evaluation based on distance from average solution (EDAS),” Informatica-Lithuan, vol. 26, no. 3, pp. 435-451, 2015.

[14] Ž. Stević, D. Pamučar, A. Puška, and P. Chatterjee, “Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS),” *Comput. Ind. Eng.*, vol. 140, Article ID: 106231, 2020.

[15] A. Puška, Ž. Stević, and D. Pamučar, “Evaluation and selection of healthcare waste incinerators using extended sustainability criteria and multi-criteria analysis methods,” *Environ. Dev. Sustain.*, vol. 24, no. 9, pp. 11195-11225, 2022.

[16] V. Starčević, V. Petrović, I. Mirović, L. Ž. Tanasić, Ž. Stević, and J. Đurović Todorović, “A novel integrated PCA-DEA-IMF SWARA-CRADIS model for evaluating the impact of FDI on the sustainability of the economic system,” *Sustainability-Basel*, vol. 14, no. 20, Article ID: 13587, 2022. https://doi.org/10.3390/su142013587.

[17] E. K. Zavadskas, Z. Turskis, J. Antucheviciene, and A. Zakarevicius, “Optimization of weighted aggregated sum product assessment,” *Elektron Elektrotech*, vol. 122, no. 6, pp. 3-6, 2012. https://doi.org/10.5755/j01.eee.122.6.1810.

[18] E. K. Zavadskas and Z. Turskis, “A new additive ratio assessment (ARAS) method in multicriteria decision-making,” *Technol. Econ. Dev. Eco.*, vol. 16, no. 2, pp. 159-172, 2010.

[19] A. Afshari, M. Mojahed, and R. M. Yusuff, “Simple additive weighting approach to personnel selection problem,” *Int. J. Innov. Manag. Techn.*, vol. 1, no. 5, pp. 511-515, 2010.