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IMPACT OF THE NUMBER OF VEHICLES ON TRAFFIC SAFETY: MULTIPHASE MODELING

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Abstract. *Traffic safety is one of the key issues nowadays, given the fact that a large number of people lose their lives in traffic accidents every day. There are various influential factors in the occurrence of traffic accidents, the number of vehicles being one of them. This paper assesses the traffic safety in Montenegro in the period 1998-2020 by applying the multiphase modeling with a purpose to obtain comparative results which enable implementation of adequate strategies. A total of six scenarios were formed with two inputs and two outputs in a DEA (Data Envelopment Analysis) model, with the number of registered vehicles per year being an input in all scenarios. In addition, as inputs, the scenarios included AADT (Annual Average Daily Traffic), passengers in road transport, passenger-km by road transport, goods transported by road, tone-km by road, and passengers in local transport. The number of traffic accidents with casualties, the number of traffic accidents with material damage, the number of fatal cases and the number of injured persons, depending on a scenario, were observed as outputs. After the DEA model, IMF SWARA (Improved Fuzzy Stepwise Weight Assessment Ratio Analysis) was applied to determine the weights of inputs and outputs, while the final state of traffic safety by years was determined using the MARCOS (Measurement of alternatives and ranking according to COmpromise solution) method.*

Key Words: *Vehicle, Traffic Safety, IMF SWARA, MARCOS, Traffic Accident*

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1. Introduction

Globalization, as one of important factors nowadays in every field, affects the course of traffic and transport processes as well as the risks of possible occurrence of undesirable situations. Certainly, for years, traffic safety has been a burning issue that is a subject of daily professional and scientific analysis. Its significance does not need to be emphasized and described too much since every participant in traffic strives to make it as safe as possible. It is necessary to find adequate measures and balance between frequently conflict situations. Modern motor vehicles with exceptional performance, excellent mechanical characteristics, equipped in a way to provide greater comfort and safety represent, on the one hand, a significant contribution to this area. However, on the other hand, if it is added a shorter time needed to reach high speeds, which also frequently leads to unsafe overtaking, we have an increased risk of accidents. It reflects the interaction between vehicles and people as important factors that can influence the emergence of risky traffic situations. This paper analyzes traffic safety in Montenegro for a period of 23 years through creating multiphase modeling. It involves creating different scenarios with different impact parameters and integrating multiple approaches into a single model.

According to Podvezko and Sivilevičius [1], a system of road transport involves vehicles, roads, traffic participants and freight that are interconnected. Transportation infrastructure and logistics are core elements supporting trade facilitation efforts at the local level [2] and, consequently, mobility and an increasing number of vehicles involved in traffic. Therefore, this paper analyzes the impact of various factors: the number of registered motor vehicles, AADT, passengers in road transport, passenger-km by road transport, goods transported by road, tonne-km by road, and passengers in local transport. The number of traffic accidents with casualties, the number of traffic accidents with material damage, the number of dead persons and the number of injured persons, depending on a scenario, were observed as outputs.

Motivation for writing this paper can be explained through the necessity of existing original and quality quantitative model which can be base for bringing adequate strategies which should increase traffic safety field. The goal of creating an integrated model implies the overall quantification of the safety for a specified period and the possibility of identifying a benchmark year according to which further strategies will be created. The main contribution of the study is the developed integrated DEA-IMF SWARA-MARCOS model presented for the first time in literature which can be used for solving various transport, traffic, and others problems. Another contribution is the fact that it is through the applied model that the possibility for preventive engineering in traffic safety can be created.

The rest of the paper is described through the following five sections. Section 2 provides a brief review of the application of different methodologies in the field of traffic safety. Section 3 presents materials and methods, giving a detailed overview of all the data used in this paper. Additionally, scenarios with a description of influential input-output factors are formed, and the methods that make up the developed integrated model are presented in detail. In Section 4, the results obtained for all scenarios are presented and discussed. Section 5 is the analysis of the impact of the number of motor vehicles on the occurrence of traffic accidents using regression analysis. The final, Section 6, summarizes the conclusions along with guidelines for continuing the research.

2. LITERATURE REVIEW

The DEA model has often been applied in the field of traffic safety, sometimes individually, and very often in integration with other approaches to ensure the most accurate decision-making. This section of the paper presents the studies that used DEA in a whole model or a phase of a model for determining traffic safety.

2.1. The application of DEA model in traffic safety

Mozaffaria et al. [3] applied the DEA model to assess traffic safety culture in order to achieve desired safety performance. They observed a three-year period and analyzed a total of 31 provinces in Iran. Based on the results obtained, they concluded that road safety culture increased on average. The double-frontier DEA was applied in [4, 5] to assess the efficiency of Iranian safety programs in order to reduce the number of traffic accidents with fatalities. A serial two-stage additive DEA model [6] was applied to analyze traffic safety performance in 31 provinces in China. The results showed certain differences between the regions in the level of traffic safety, and suggested certain procedures for adequate traffic safety management. The authors of the paper [7] have evaluated 197 municipalities in terms of traffic safety, applying a DEA model, which consists of several phases. In the same paper, different scenarios with two inputs and 14, eight and six outputs, respectively, were modeled. Fancello et al. [8] compared CCR and BCC models in order to support traffic management in terms of urban road safety. The goal was to identify the critical roads that have the greatest need for intervention and increase in traffic safety. The fuzzy form of DEA method can be successfully applied in the traffic safety field. For example, fuzzy DEA has been applied in [9] to evaluating road safety index in Iran.

2.2. The application of integrated models in traffic safety

Infrastructure improvement is one of significant instruments for increasing traffic safety, as stated in the paper [10] in which DEA and GIS (geographical information system) were combined to assess the risk level of problematic road segments with a length of 100 km. In that way, traffic safety is improved through locating and visualizing problematic points on the observed road segment. In [11], a combination of PCA-DEA model was used considering undesirable input and output indices. The authors state that the advantage of the applied approach is the benchmarking of the safest roads in order to best allocate budget funds in the field of traffic safety.

Stanković et al. [12] extended the MARCOS method with fuzzy numbers to determine traffic safety in Bosnia and Herzegovina on defined road sections. A total of 38 short sections of 200 m each were evaluated based on six influential factors. The original CRITIC (The CRiteria Importance Through Intercriteria Correlation), Fuzzy FUCOM (Full Consistency Method), DEA, and Fuzzy MARCOS model were created in [13] which evaluated nine sections of the road network based on eight criteria divided into four inputs and four outputs. The methodology for assessing road sections is similar to that in this paper because a DEA method was applied first, and then the others depending on their purposefulness. The integration of BWM (Best Worst Method) with a DEA model being modified to be applicable and adaptable in the field of traffic safety has been applied in [14]. A DEA-RS (Road Safety) model has been defined and verified through a case study in Iran. An integrated DEA and Monte-Carlo simulation prioritizing approach is proposed in [15] to determine the prioritization of traffic safety management projects. Stević et al. [16] have created an original DEA-CRITIC-MARCOS model for evaluating traffic safety on 17 important roads of South Africa city. In comparison to other studies, the authors have used DEA for calculation criteria weights instead of initial safety performance.

3. Materials and Methods

3.1. Research description and problem setting

A research flow diagram is shown in Fig. 1. It consists of forming a total of six scenarios where different inputs and outputs are modeled. A multi-phase model of traffic accident analysis, which includes a DEA-IMF SWARA-MARCOS model has been applied. DEA CCR model has been selected because of its simplicity and previous exploration in literature. However, the power discrimination of the DEA model can be low in many cases. For that reason, we have applied IMF SWARA and MARCOS model in order to obtain final results with clear differences between the variants.

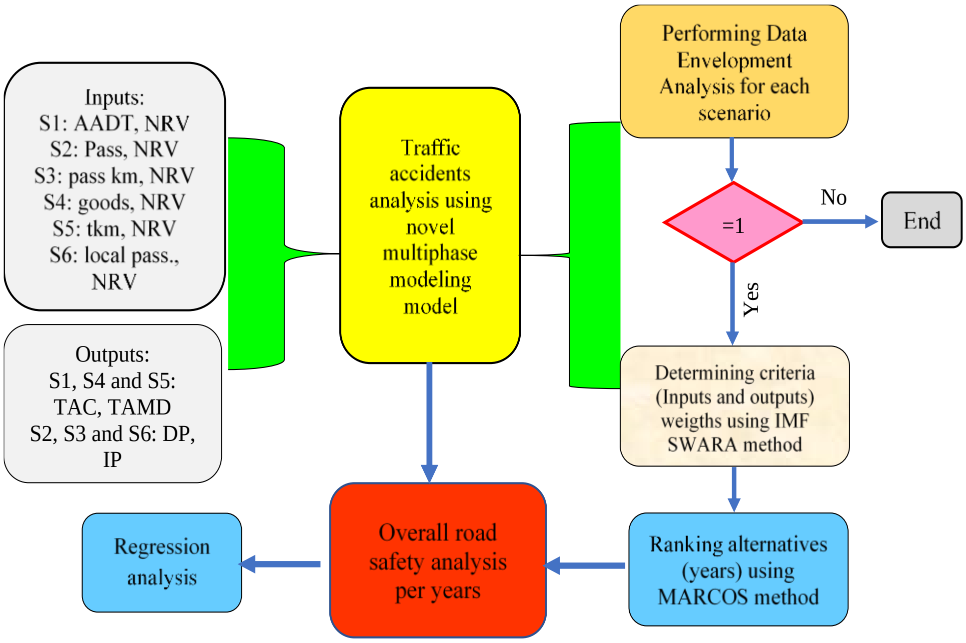

Fig. 1 A research flow diagram

Inputs are results of integration mostly literature review and dialogues with experts. The first scenario S1 includes AADT (Annual Average Daily Traffic) [13, 16] and the number of registered vehicles (NRV) [5,17,19] as inputs; and traffic accidents with casualties (TAC) and traffic accidents with material damage (TAMD) [20]. Overall data for the first scenario are presented in Table 1.

The second scenario S2 implies the number of passengers in road transport as the first input, and the number of registered vehicles (which are one of the inputs in each scenario). In this scenario, the number of dead persons (DP) [21] and the number of injured persons (IP) [14, 20] are outputs. The data for the second scenario are presented in Fig. 2.

Table 1. Data for the DEA model for the first scenario S1

	AADT	NRV	TAC	TAMD
2009	7388	183,441	1718	8394
2010	7164	187,913	1520	7618
2011	7140	196,419	1451	7068
2012	5593	197,826	1217	6886
2013	4733	203,266	1266	3998
2014	6440	196,059	1334	4197
2015	7471	198,772	1554	3390
2016	7912	209,098	1698	3531
2017	7969	219,378	1831	3847
2018	8953	235,385	1855	4017
2019	4078	249,301	1924	4286
2020	3052	240,611	1490	3102

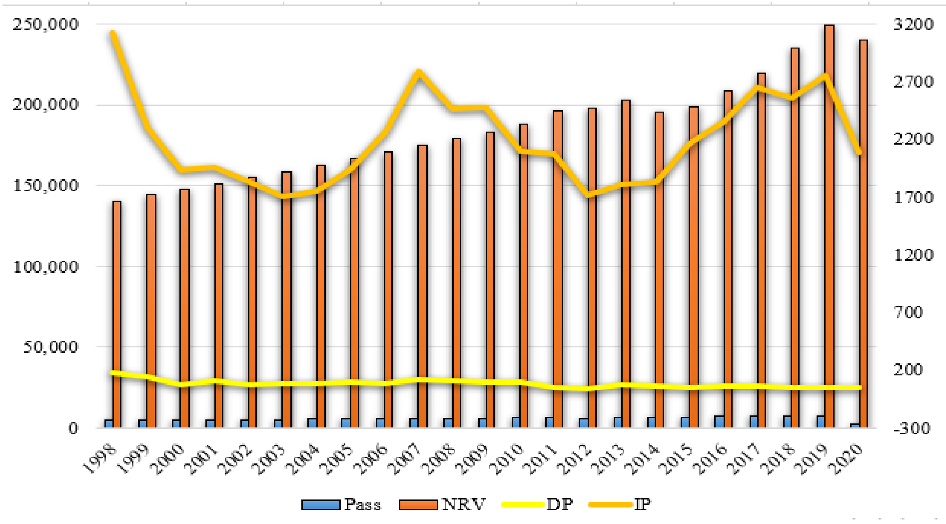

Fig. 2 Data for the DEA model for the second scenario S2

The third scenario implies only one change compared to the previous, second scenario, and it is reflected through the change of the first input. Instead of passengers in road transport, the results with passenger-km by road transport [20, 22] were modeled and the data are presented in Fig. 3.

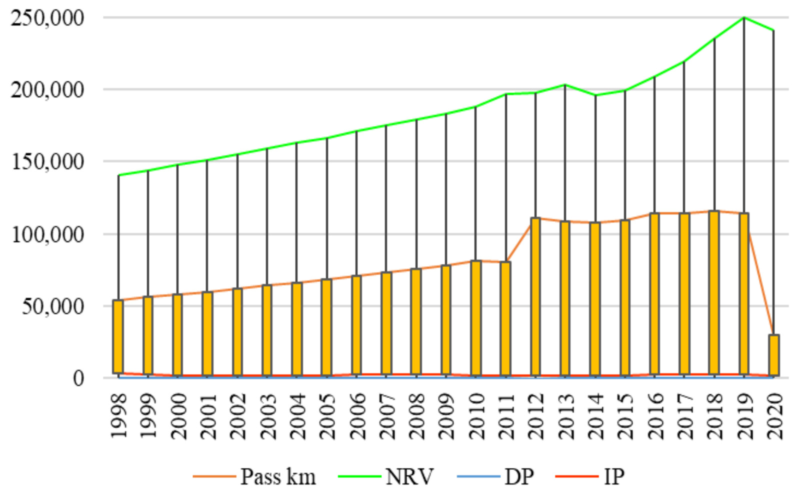

Fig. 3 Data for the DEA model for the third scenario S3

Fig. 4 shows the data for the fourth and fifth scenarios since the only difference is in the first input. Transport according to Sénquiz-Díaz [23] remains a key development factor in any country and has an influence on the transport of goods. In the fourth scenario, the first input is goods transported by road [6] in thousands, while tkm [14] is the first input in the fifth scenario.

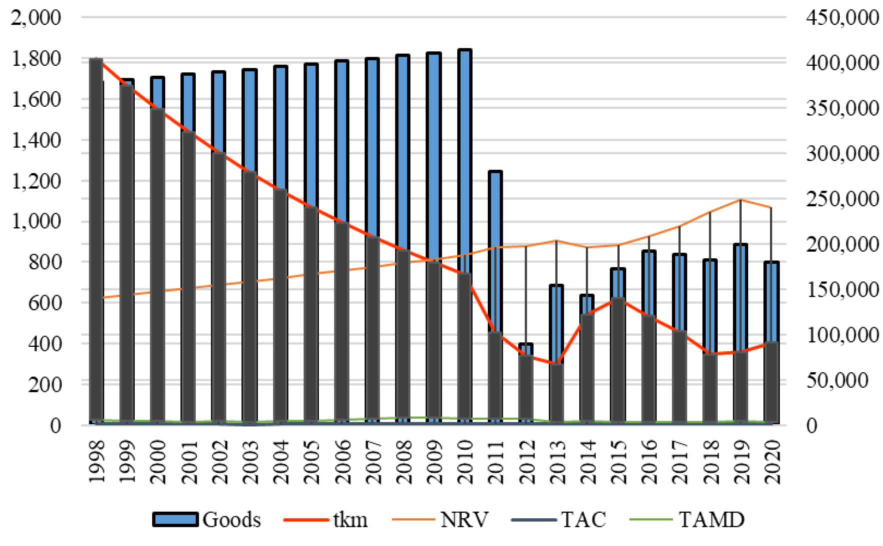

Fig. 4 Data for the DEA model for the fourth (S4) and fifth scenario (S5)

Fig. 5 shows the data for the last, sixth scenario (S6) for the DEA model in which the inputs are passengers in local road transport and the number of registered vehicles, and the outputs are the number of dead persons and the number of injured persons in traffic accidents.

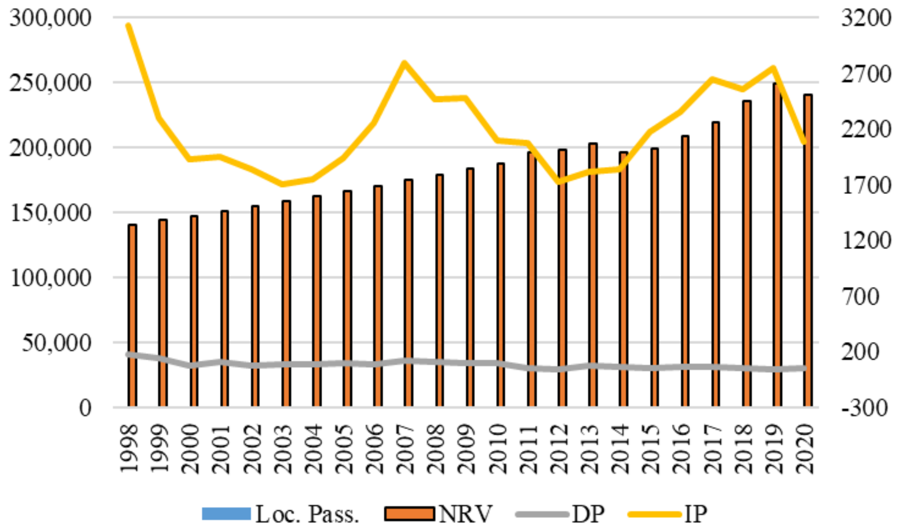

Fig. 5 Data for the DEA model for the sixth scenario

After that, the DEA model was applied for each scenario separately. In the first scenario, it was observed the period 2009-2020 considering the availability of data for AADT, while the period from 1998 to 2020 was observed in other scenarios. Data on traffic accidents sorted by categories are available for the whole period, while data on the number of registered motor vehicles, passengers in road transport, passenger-km, goods transported by road, tonne-kilometers by road and passengers in local transport are available for limited periods, maximum for 15 years. In order to obtain the most relevant analysis for each of these elements, the annual increase or decrease was calculated, and based on that, the average annual trend was calculated. Finally, data for the previous historical period that was missing were obtained by applying a linear model based on the calculated annual trend. It is important to note that 2020 is not taken into account in these calculations due to the conditions of COVID-19 and the limitations caused by the pandemic. Also, the goods transported by road were not taken for 2012 as an input since there was a drastic decline compared to the previous two years.

Clear advantages of the applied methods are presented in [24] and [25], respectively.

3.2. DEA method

Here, a DEA (Data Envelopment Analysis) CCR input model [26-28] is formed for traffic safety evaluation. An input oriented model is:

$$\begin{aligned} & DEA_{input} = \max \sum_{i=1}^{m} w_i x_{i-input} \\ & st: \\ & \sum_{i=1}^{m} w_i x_{ij} - \sum_{i=m+1}^{m+s} w_i y_{ij} \leq 0, \quad j = 1,...,n \\ & \sum_{i=m+1}^{m+s} w_i y_{i-output} = 1 \\ & w_i \geq 0, \quad i = 1,...,m+s \end{aligned} \tag{1}$$

In this model, a Decision-Making Unit (DMU) consists of *m* inputs for each *xij*, while *s* represents outputs for each *yij*.

3.3. IMF SWARA method

The IMF SWARA method is a recently developed method presented byVrtagić et al. [24]. It consists of the following steps [29, 30].

Step 1: The criteria were arranged in descending order based on their expected significance.

Step 2: Starting from the previously determined rank, the significance of the criterion (*Cj*) was determined in relation to the previous one (*Cj*−1) according to the scale represented in Table 2, and this was repeated for each subsequent criterion. This relation is marked with $\overline{\varsigma_j}$.

Table 2 Linguistics and the TFN scale for comparing criteria in the IMF SWARA method

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: The fuzzy coefficient was determined $\overline{\vartheta_j}$:

$$\overline{\vartheta_j} = \begin{cases} (1,1,1) & j = 1 \\ \overline{\varsigma_j} & j > 1 \end{cases} \tag{2}$$

Step 4: The calculated weights were determined $\overline{\varepsilon_j}$:

$$\overline{\varepsilon_j} = \begin{cases} (1,1,1) & j = 1 \\ \dfrac{\overline{\varepsilon_{j-1}}}{\overline{\vartheta_j}} & j > 1 \end{cases} \tag{3}$$

Step 5: The fuzzy weight coefficients were calculated using the following Eq. (4):

$$\overline{w_j} = \frac{\overline{\varepsilon_j}}{\sum_{j=1}^{m} \overline{\varepsilon_j}} \tag{4}$$

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

3.4. MARCOS method

The Measurement Alternatives and Ranking according to COmpromise Solution (MARCOS) method [25] is based on defining the relationship between alternatives and reference values (ideal and anti-ideal alternatives). The MARCOS method is performed through the following steps [31, 32].

Step 1: Formation of an initial decision-making matrix.

Step 2: Formation of an extended initial matrix with the ideal (AI) and anti-ideal (AAI) solution.

$$X = \begin{array}{c} \\ AAI \\ A_1 \\ A_2 \\ \ldots \\ A_m \\ AI \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} x_{aa1} & x_{aa2} & \ldots & x_{aan} \\ x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{22} & \ldots & x_{mn} \\ x_{ai1} & x_{ai2} & \ldots & x_{ain} \end{bmatrix} \end{array} \tag{5}$$

$$AAI = \min_i x_{ij} \quad if \;\; j \in B \quad and \quad \max_i x_{ij} \quad if \;\; j \in C \tag{6}$$

$$AI = \max_i x_{ij} \quad if \;\; j \in B \quad and \quad \min_i x_{ij} \quad if \;\; j \in C \tag{7}$$

Step 3: Normalization of extended initial matrix (X).

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \quad if \;\; j \in C \tag{8}$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}} \quad if \;\; j \in B \tag{9}$$

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

Step 4: Determination of weighted matrix $V = [v_{ij}]_{m \times n}$.

$$v_{ij} = n_{ij} \times w_j \tag{10}$$

Step 5: Calculation of the utility degree of alternatives *Ki*.

$$K_i^- = \frac{S_i}{S_{aai}} \tag{11}$$

$$K_i^+ = \frac{S_i}{S_{ai}} \tag{12}$$

where S_i (i=1,2,..,m) represents the sum of the elements of weighted matrix *V*, Eq. (13).

$$S_i = \sum_{i=1}^{n} v_{ij} \tag{13}$$

Step 6: Determination of the utility function of alternatives *f(K_i)*.

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}}; \tag{14}$$

where $f(K_i^-)$ represents the utility function in relation to the anti-ideal solution, while $f(K_i^+)$ 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 Eqs. (15) and (16).

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \tag{15}$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \tag{16}$$

Step 7: 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.

4. RESULTS

This section presents in detail the results obtained by applying multiphase modeling of the impact of various factors, primarily motor vehicles on traffic safety in Montenegro over a period of 23 years (1998-2020).

4.1. Results after applying the DEA model

The results of the DEA model for all six scenarios are shown in Table 3.

Table 3 DEA model results for all scenarios

	S1	S2	S3	S4	S5	S6
1998		0.415	0.391	0.719	0.948	0.555
1999		0.577	0.544	0.756	0.921	0.591
2000		0.703	0.664	0.892	1.000	0.712
2001		0.711	0.672	0.976	1.000	0.712
2002		0.777	0.734	0.952	0.987	0.786
2003		0.857	0.811	1.000	1.000	0.840
2004		0.853	0.808	0.977	0.962	0.823
2005		0.787	0.746	0.903	0.876	0.764
2006		0.693	0.657	0.799	0.765	0.678
2007		0.573	0.544	0.676	0.640	0.576
2008		0.663	0.630	0.735	0.688	0.627
2009	0.874	0.677	0.644	0.769	0.712	0.658
2010	0.958	0.818	0.778	0.887	0.815	0.761
2011	1.000	0.885	0.823	0.900	0.850	0.884
2012	1.000	1.000	1.000	1.000	1.000	1.000
2013	1.000	0.996	0.976	0.995	0.992	1.000
2014	1.000	1.000	0.930	0.910	0.939	1.000
2015	1.000	1.000	0.888	0.805	0.900	1.000
2016	1.000	0.941	0.772	0.832	0.852	1.000
2017	0.951	0.886	0.768	0.779	0.775	0.952
2018	1.000	1.000	0.990	0.788	0.786	0.955
2019	0.822	1.000	1.000	0.807	0.802	0.953
2020	1.000	1.000	1.000	1.000	1.000	1.000

The results after applying the DEA model show that in the period 1998-2010, 2003 has a satisfactory situation in terms of traffic safety only in scenarios S4 (inputs are NRV and goods) and S5 (inputs are NRV and tkm). In other years, there is no adequate level, which is in a way understandable because over time it is resorted to modern preventive engineering that gives certain results. In the first scenario when NRV and AADT were considered as inputs in the period 2009-2020, a significant number of years (eight out of 12) show a satisfactory level of safety. Taking this into account, modeling using other inputs in combination with the number of registered motor vehicles proves to be justified. The two years that can be singled out as a benchmark based on the DEA model are 2012 and 2020. However, it is necessary to make their comparative analysis. AADT in 2020 is lower (3052) compared to 2012 (5593), surely due to the limitations caused by the pandemic, so 2012 is certainly better in such conditions. The situation is similar with the scenarios S2, S3 and S5 when it comes to passengers and passenger-km, while the situation in S4 is different since in 2012, compared to all other years, the lowest amount of goods transported by road was recorded, namely only 398 thousand tons. In the sixth scenario, the values of these two observation years are approximate when it comes to the number of local passengers.

Fig. 6 shows a statistical analysis that involves the calculation of the Spearman [33] and WS [34] correlation coefficients.

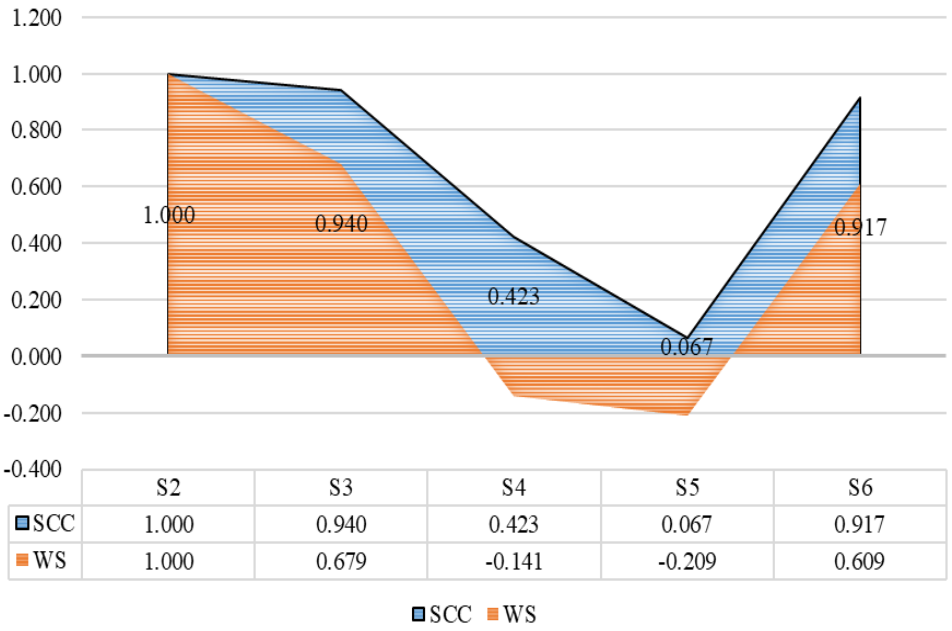

Fig. 6 SCC and WS after applying the DEA model

Fig. 6 shows large deviations in ranks using different scenarios (S2-S6). The second, third and sixth scenarios have the highest correlation, which is very high according to the SCC, while it is lower according to the WS coefficient because these are changes in the initial ranks. Other correlations are very low.

4.2. Results of determining the weights of the criteria using the IMF SWARA method

After the application of the DEA model, the final results have not been obtained since a large number of DMUs, i.e. observation years, have a value of one, depending on a scenario, so it is necessary to apply the MCDM model for their final ranking. This section presents the results of determining the significance of the criteria using the IMF SWARA method (Table 4).

Table 4 Calculation process and weights of criteria applying the IMF SWARA method

S1	$\overline{s}_j$			$\overline{k}_j$			$\overline{q}_j$			$\overline{w}_j$			crisp value
TAC				1.00	1.00	1.00	1.00	1.00	1.00	0.30	0.31	0.32	0.31
AADT	0.22	0.25	0.29	1.22	1.25	1.29	0.78	0.80	0.82	0.23	0.25	0.26	0.25
NRV	0.00	0.00	0.00	1.00	1.00	1.00	0.78	0.80	0.82	0.23	0.25	0.26	0.25
TAMD	0.22	0.25	0.29	1.22	1.25	1.29	0.60	0.64	0.67	0.18	0.20	0.21	0.20
							3.16	3.24	3.31				
S2	$\overline{s}_j$			$\overline{k}_j$			$\overline{q}_j$			$\overline{w}_j$			crisp value
DP				1.00	1.00	1.00	1.00	1.00	1.00	0.32	0.33	0.34	0.33
IP	0.25	0.29	0.33	1.25	1.29	1.33	0.75	0.78	0.80	0.24	0.26	0.27	0.26
NRV	0.22	0.25	0.29	1.22	1.25	1.29	0.58	0.62	0.65	0.19	0.21	0.22	0.21
PASS. ROAD	0.00	0.00	0.00	1.00	1.00	1.00	0.58	0.62	0.65	0.19	0.21	0.22	0.21
							2.92	3.02	3.11				
S3	$\overline{s}_j$			$\overline{k}_j$			$\overline{q}_j$			$\overline{w}_j$			crisp value
DP				1.00	1.00	1.00	1.00	1.00	1.00	0.30	0.31	0.32	0.31
IP	0.29	0.33	0.40	1.29	1.33	1.40	0.71	0.75	0.78	0.21	0.23	0.25	0.23
NRV	0.00	0.00	0.00	1.00	1.00	1.00	0.71	0.75	0.78	0.21	0.23	0.25	0.23
PASS. ROAD	0.00	0.00	0.00	1.00	1.00	1.00	0.71	0.75	0.78	0.21	0.23	0.25	0.23
							3.14	3.25	3.33				
S4	$\overline{s}_j$			$\overline{k}_j$			$\overline{q}_j$			$\overline{w}_j$			crisp value
TAC				1.00	1.00	1.00	1.00	1.00	1.00	0.30	0.31	0.32	0.31
NRV	0.22	0.25	0.29	1.22	1.25	1.29	0.78	0.80	0.82	0.23	0.25	0.26	0.25
TAMD	0.00	0.00	0.00	1.00	1.00	1.00	0.78	0.80	0.82	0.23	0.25	0.26	0.25
Goods	0.22	0.25	0.29	1.22	1.25	1.29	0.61	0.64	0.67	0.18	0.20	0.21	0.20
							3.16	3.24	3.31				
S5	$\overline{s}_j$			$\overline{k}_j$			$\overline{q}_j$			$\overline{w}_j$			crisp value
TAC				1.00	1.00	1.00	1.00	1.00	1.00	0.30	0.31	0.32	0.31
NRV	0.22	0.25	0.29	1.22	1.25	1.29	0.78	0.80	0.82	0.23	0.25	0.26	0.25
TAMD	0.00	0.00	0.00	1.00	1.00	1.00	0.78	0.80	0.82	0.23	0.25	0.26	0.25
tkm	0.22	0.25	0.29	1.22	1.25	1.29	0.61	0.64	0.67	0.18	0.20	0.21	0.20
							3.16	3.24	3.31				
S6	$\overline{s}_j$			$\overline{k}_j$			$\overline{q}_j$			$\overline{w}_j$			crisp value
DP				1.00	1.00	1.00	1.00	1.00	1.00	0.33	0.34	0.35	0.34
IP	0.22	0.25	0.29	1.22	1.25	1.29	0.78	0.80	0.82	0.26	0.27	0.29	0.27
NRV	0.22	0.25	0.29	1.22	1.25	1.29	0.60	0.64	0.67	0.20	0.22	0.23	0.22
PASS. local	0.22	0.25	0.29	1.22	1.25	1.29	0.47	0.51	0.55	0.15	0.17	0.19	0.17
							2.85	2.95	3.03				

From the results obtained using the IMF SWARA method it can be concluded that the most important factors are TAC in the first, fourth, and fifth scenarios, while DP is the most important criterion in the second, third and sixth scenarios. NRV is the second or third most important criterion in all the scenarios, while the other factors related to local passengers, goods and tkm are less important criteria, but not with significant differences.

4.3. Determining the final rank by applying the MARCOS method

The years with a value of 1.000 after the application of the DEA model, shown in Table 3, represent alternatives in the further implementation of the MARCOS method. This section of the paper will provide the results for all the scenarios, and a detailed presentation of the calculation only for the first scenario in which the criteria are AADT, the number of registered motor vehicles, the number of traffic accidents with casualties and the number of traffic accidents with material damage. Out of a total of 12 observation years, eight have a value of one, which means that in those years, traffic safety in relation to the observed data set is at a relatively satisfactory level. In 2009, 2010, 2017 and 2019, there is a large number of traffic accidents of both classifications, and 2019 stands out in particular, with 1924 traffic accidents with casualties, despite the very low AADT (4078) compared to other years.

In the first step of the MARCOS method, the initial matrix is formed, while in the second step, by applying Eqs. (6) and (7), the ideal and anti-ideal solutions are determined and, based on that, an extended initial decision matrix shown in Table 5 is formed.

Table 5 Initial Extended Matrix

	AADT	NRV	TAC	TAMD
Antiideal	3052.000	196059.000	1855.000	7068.000
2011	7140	196,419	1451	7068
2012	5593	197,826	1217	6886
2013	4733	203,266	1266	3998
2014	6440	196,059	1334	4197
2015	7471	198,772	1554	3390
2016	7912	209,098	1698	3531
2018	8953	235,385	1855	4017
2020	3052	240,611	1490	3102
Ideal	8953.000	240611.000	1217.000	3102.000

It is important to note that the first and second criteria belong to the benefit criteria where a maximum value is desirable, while the third and fourth criteria belong to those for which the minimum value is desirable.

In the third step, the data presented in Table 5 are normalized based on Eqs. (8) and (9) as follows.

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \quad if \;\; j \in C \quad \Rightarrow \quad n_{13} = \frac{1217}{1451} = 0.839$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}} \quad if \;\; j \in B \quad \Rightarrow \quad n_{11} = \frac{7140}{8953} = 0.797$$

Other normalized values are obtained in an identical way depending on the orientation of the criteria and are presented in Table 6.

Table 6 Normalized matrix

	AADT	NRV	TAC	TAMD
Antiideal	0.341	0.815	0.656	0.439
2011	0.797	0.816	0.839	0.439
2012	0.625	0.822	1.000	0.450
2013	0.529	0.845	0.961	0.776
2014	0.719	0.815	0.912	0.739
2015	0.834	0.826	0.783	0.915
2016	0.884	0.869	0.717	0.879
2018	1.000	0.978	0.656	0.772
2020	0.341	1.000	0.817	1.000
Ideal	1.000	1.000	1.000	1.000

In the fourth step of the MARCOS method, the normalized values are weighted with the weights of the criteria that have been calculated in the previous section of the paper for all the scenarios using the IMF SWARA method. The weight coefficients of the criteria for the first scenario are: w1=w2=0.247; w3=0.309 and w4=0197. The weighted decision matrix is shown in Table 7.

Table 7 Weighted decision matrix

	AADT	NRV	TAC	TAMD
Antiideal	0.084	0.201	0.203	0.086
2011	0.197	0.202	0.259	0.086
2012	0.154	0.203	0.309	0.089
2013	0.131	0.209	0.297	0.153
2014	0.178	0.201	0.282	0.146
2015	0.206	0.204	0.242	0.180
2016	0.218	0.215	0.221	0.173
2018	0.247	0.242	0.203	0.152
2020	0.084	0.247	0.252	0.197
Ideal	0.247	0.247	0.309	0.197

The rest of the calculation using the MARCOS method is given below, and the results for the first scenario are presented in Table 8. In the fifth step, using Eq. (13), the value of S_{AAI} is calculated as follows:

$$S_{AAI} = 0.084+0.201+0.203+0.086=0.575$$

$$S1 = 0.197+0.202+0.259+0.086=0.744 \text{ etc.}$$

By applying Eq. (11), the following is calculated:

$$K_i^- = \frac{S_i}{S_{aai}} \quad \Rightarrow \quad K_1^- = \frac{0.744}{0.575} = 1.295,$$

i.e. by applying Eq. (12):

$$K_i^+ = \frac{S_i}{S_{ai}} \quad \Rightarrow \quad K_1^+ = \frac{0.744}{1.000} = 0.744$$

In the sixth step, the utility function is calculated in relation to the anti-ideal solution by applying Eq. (15):

$$f(K_i^-)=\frac{K_i^+}{K_i^+ + K_i^-} \quad \Rightarrow \quad f(K_{1-8}^-)=\frac{0.744}{0.744+1.295}=0.365$$

i.e. in relation to the ideal solution by applying Eq. (16):

$$f(K_i^+)=\frac{K_i^-}{K_i^+ + K_i^-} \quad \Rightarrow \quad f(K_{1-8}^+)=\frac{1.295}{0.744+1.295}=0.635$$

The utility function of all the alternatives is calculated by applying Eq. (14):

$$f(K_i)=\frac{K_i^+ + K_i^-}{1+\frac{1-f(K_i^+)}{f(K_i^+)}+\frac{1-f(K_i^-)}{f(K_i^-)}} \Rightarrow f\left(K_1\right)=\frac{0.744+1.295}{1+\frac{1-0.635}{0.635}+\frac{1-0.365}{0.365}}=0.615$$

Table 8 Results for the first scenario after applying the DEA-IMF SWARA-MARCOS model

Ai	Si	Ki-	Ki+	f(K-)	f(K+)	f(Ki)	Rank
AAI	0.575						
2011	0.744	1.295	0.744	0.365	0.635	0.615	8
2012	0.755	1.314	0.755	0.365	0.635	0.624	7
2013	0.789	1.373	0.789	0.365	0.635	0.652	5
2014	0.806	1.403	0.806	0.365	0.635	0.667	4
2015	0.832	1.449	0.832	0.365	0.635	0.688	2
2016	0.827	1.440	0.827	0.365	0.635	0.684	3
2018	0.843	1.468	0.843	0.365	0.635	0.697	1
2020	0.781	1.358	0.781	0.365	0.635	0.645	6
AI	1.000						

Based on the results presented in Table 8, it can be concluded that the range of differences in final values among alternatives is very small (0.082). It means that, regardless of the fact that there are certain differences, traffic safety according to the first scenario in all years is approximate, i.e. there are very slight nuances. It is confirmed by the fact that there is no alternative that tends to one.

The results for the remaining five scenarios are obtained in the same way, as shown in Tables 9-13.

Table 9 Results for the second scenario after applying the DEA-IMF SWARA-MARCOS model

Ai	Si	Scenario 2 – S2					
AAI	0.630	Ki-	Ki+	f(K-)	f(K+)	f(Ki)	Rank
2012	0.906	1.438	0.905	0.386	0.614	0.728	1
2014	0.823	1.307	0.822	0.386	0.614	0.661	5
2015	0.854	1.357	0.854	0.386	0.614	0.687	4
2018	0.889	1.412	0.889	0.386	0.614	0.715	3
2019	0.897	1.425	0.897	0.386	0.614	0.721	2
2020	0.801	1.272	0.801	0.386	0.614	0.644	6
AI	1.000						

Table 10 Results for the third scenario after applying the DEA-IMF SWARA-MARCOS model

Ai	Si	Scenario 3 – S3					
AAI	0.683	Ki-	Ki+	f(K-)	f(K+)	f(Ki)	Rank
2012	0.947	1.387	0.946	0.406	0.594	0.741	1
2019	0.908	1.330	0.907	0.406	0.594	0.710	2
2020	0.768	1.126	0.768	0.406	0.594	0.602	3
AI	1.000						

Table 11 Results for the fourth scenario after applying the DEA-IMF SWARA-MARCOS model

Ai	Si	Scenario 4 – S4					
AAI	0.561	Ki-	Ki+	f(K-)	f(K+)	f(Ki)	Rank
2003	0.865	1.540	0.864	0.359	0.641	0.719	1
2012	0.656	1.168	0.656	0.359	0.641	0.546	3
2020	0.827	1.472	0.826	0.359	0.641	0.688	2
AI	1.000						

Table 12 Results for the fifth scenario after applying the DEA-IMF SWARA-MARCOS model

Ai	Si	Scenario 5 – S5					
AAI	0.548	Ki-	Ki+	f(K-)	f(K+)	f(Ki)	Rank
2000	0.808	1.474	0.808	0.354	0.646	0.677	2
2001	0.807	1.471	0.807	0.354	0.646	0.676	3
2003	0.825	1.505	0.825	0.354	0.646	0.691	1
2012	0.654	1.193	0.654	0.354	0.646	0.548	5
2020	0.788	1.437	0.787	0.354	0.646	0.659	4
AI	1.000						

Table 13 Results for the sixth scenario after applying the DEA-IMF SWARA-MARCOS model

Ai	Si	Scenario 6 – S6					
AAI	0.703	Ki-	Ki+	f(K-)	f(K+)	f(Ki)	Rank
2012	0.906	1.289	0.906	0.413	0.587	0.702	1
2013	0.780	1.110	0.780	0.413	0.587	0.605	6
2014	0.813	1.157	0.813	0.413	0.587	0.631	4
2015	0.863	1.228	0.863	0.413	0.587	0.669	3
2016	0.799	1.137	0.799	0.413	0.587	0.620	5
2020	0.894	1.272	0.894	0.413	0.587	0.693	2
AI	1.000						

Fig. 7 shows a comparative analysis of the ranks through the complete DEA-IMF SWARA-MARCOS model

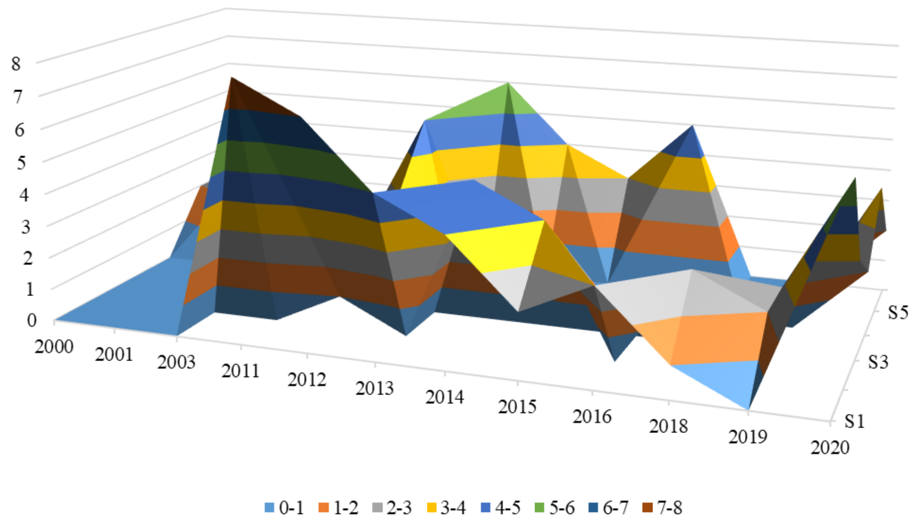

Fig. 7 Comparative analysis of the ranks through all the scenarios

In Fig. 7, it can be seen that by applying the DEA-IMF SWARA-MARCOS model, the ranks vary in relation to the set criteria, but here, 2012 can also be singled out as a benchmark.

5. Impact of the Number of Registered Vehicles on Traffic Accidents

In this section of the paper, a short regression analysis is performed of the impact of the number of registered vehicles as an independent variable on the number of dead persons in traffic accidents (Fig. 8), traffic accidents with casualties (Fig. 9) and traffic accidents with material damage (Fig. 10).

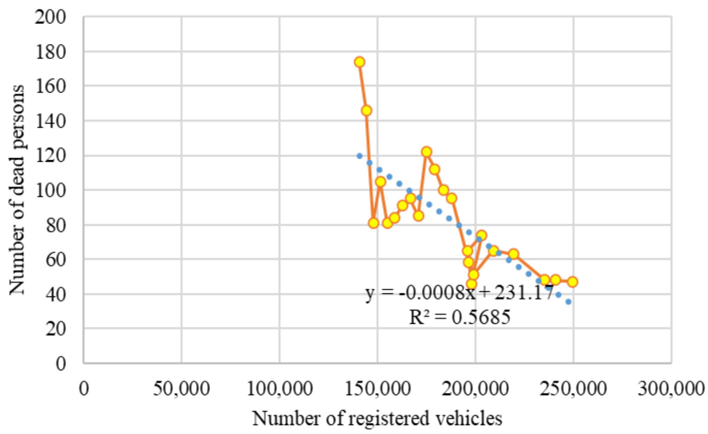

Fig. 8 The impact of vehicles on the number of dead persons in traffic accidents

In Fig. 8, it can be seen that 57% of the relation between the number of registered vehicles and the number of dead persons can be described by a linear model. The regression is negative, which means that with the increase in the number of motor vehicles, the number of dead persons in traffic accidents decreases. The reason for this regression can be found in the fact that competent institutions have taken certain measures every year due to preventive engineering when it comes to the number of dead persons in traffic accidents in Montenegro.

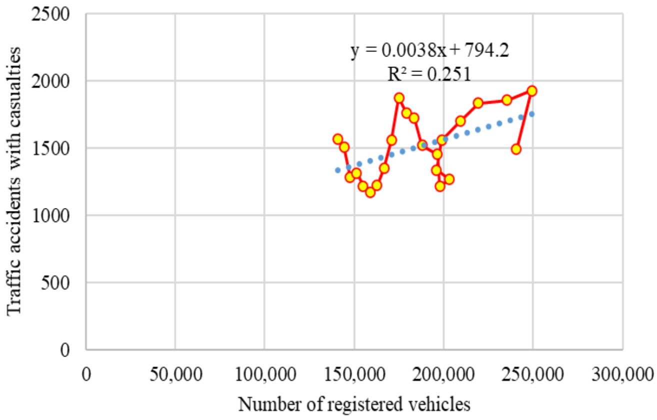

Fig. 9 Influence of vehicles on the number of traffic accidents with casualties

In Fig. 9, it can be seen that 25% of the relation between the number of registered vehicles and the number of traffic accidents with casualties can be described by a linear model. The regression is positive, which means that with the increase in the number of motor vehicles, the number of this type of traffic accidents also increases. Compared to the previous regression, this shows us that the number of motor vehicles affects the increase in the number of traffic accidents with casualties, but that these are primarily injured persons.

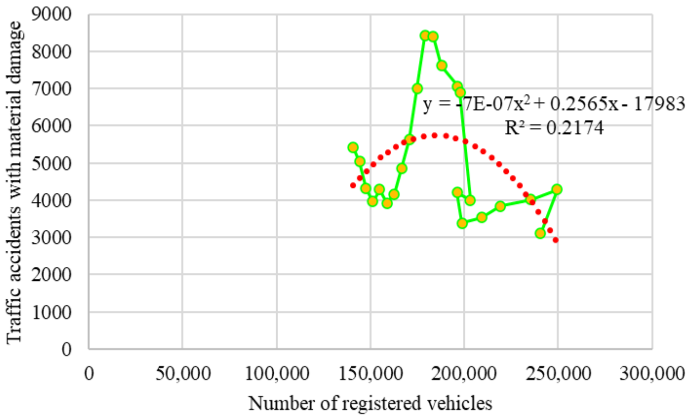

Fig. 10 Influence of vehicles on the number of traffic accidents with material damage

Fig. 10 shows a negative regression described by a polynomial model. The number of motor vehicles does not affect the increase in traffic accidents with material damage.

6. CONCLUSIONS

In this paper, it was developed an integrated DEA – IMF SWARA – MARCOS model for assessing traffic safety in Montenegro over a period of 23 years. Different scenarios have been formed using different input and output factors, with the number of vehicles being an irreplaceable input parameter. The contribution of this paper is reflected in the development of an integrated multiphase model for the analysis of traffic safety in Montenegro. The first phase involves the application of a DEA model for all the scenarios, after which DMUs with a value of 1.00 are further implemented in the MCDM model. The IMF SWAFA method was applied to determine the significance of input and output parameters in each scenario, and the final ranking of alternatives was performed using the MARCOS method. The results obtained show that in terms of traffic safety in Montenegro, compared to the end of the previous and the beginning of this century, the situation has improved with certain oscillations over the years. A regression analysis of the impact of the number of motor vehicles on traffic accidents and of its consequences was also performed. With the increase in the number of motor vehicles, the number of traffic accidents with casualties also increases. The benchmark years that should serve as an example of implementing measures and creating a traffic safety strategy are 2012 and 2020, but it should be taken into account that mobility was reduced during the pandemic. Therefore, it may be better to take 2012 as a parameter year.

Limitations of this study can be manifested through the following. Some of the uncertainties appear in the year 2020 which has been part of observed years due to COVID-19. We have tried to eliminate this uncertainty by creating a linear model in considering data that has been explained in the paper and giving the advantage of the 2012 year in comparison to 2020. Future research related to this paper refers to the expansion of influential factors, the application of uncertainty theories in the whole model. Additionally, the implementation of adequate preventive engineering measures after this analysis is one of the future steps.

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