FUCOM-MARCOS Model for Selection of Parking Places for Vehicles of Dangerous Goods: Example of Selected Road Section

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Abstract

One important activity that is insufficiently researched in the field of supply chain for dangerous goods concerns the locations where vehicles carrying dangerous goods are parked. In the territory of Serbia, where the research was conducted, there are no prescribed locations of this type. This paper presents an example of selecting suitable parking locations for vehicles carrying dangerous goods along a road section of the highway network in the Republic of Serbia. For that purpose, the integrated MCDM model, consisting of the FUCOM and MARCOS methods, has been applied. FUCOM is used to determine the weighting coefficients, while the MARCOS method is used to rank locations. The results represent the selection of the most suitable locations in relation to the length of the observed section and the direction. Verification of the proposed model was performed through sensitivity and comparative analyses, and the calculation of correlation coefficients.

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Introduction

The volume of consumption of dangerous goods across various fields is increasing constantly and poses a challenge for the management process throughout the entire supply chain of dangerous goods. This field involves a broader range of participants and requires a high level of skills and knowledge from managers involved in this type of supply chain. One of the most important tasks in the field of dangerous goods is preventive actions, which require performing many strenuous activities. This paper aims to demonstrate the significance of introducing parking facilities for vehicles carrying dangerous goods on the Republic of Serbia's highway network. We have selected one road section with one direction: 3a - section D3 on the road direction Horgoš - Belgrade border crossing, length 210 km, direction Belgrade. There are 12 potential locations for this road section, as mentioned, with the given direction, and four influencing factors for their evaluation. Based on the opinions of the interviewed experts and the length of this section, it is necessary to choose three locations per direction that could later be used to form scenarios for the whole highway network. More details can be found in the paper (Smiljanić et al., 2024).

The methodology in this paper involves the application of two well-known MCDM (Multi-Criteria Decision-Making) methods: FUCOM (Full Consistency Method) and MARCOS (Measurement of Alternatives and Ranking according to COmpromise Solution) for selecting the most suitable locations among the 12 considered. These methods belong to newer MCDM methods, which are dominant for solving various tasks.

The structure of the rest of the paper is as follows. The second section presents algorithms for the applied FUCOM and MARCOS methods. The third section presents elements of the MCDM model and the results obtained, including the determination of the criteria weights and the selection of the three most suitable locations. In the fourth section, we performed a comparative analysis with other MCDM methods, varying the criteria weights across 24 scenarios and calculating correlation coefficients.

Methodology

For this paper, we have used two very popular MCDM methods, FUCOM and MARCOS, which have been widely explored for various purposes (Fazeli & Peng, 2023; Everest et al., 2024; Duc Trung, 2022; Mantos et al., 2023).

FUCOM method

The FUCOM method (Pamučar et al., 2018) is a subjective MCDM method for determining criteria. This method aims to calculate criterion weights with minimal subjectivity, thereby reducing the potential for bias introduced by expert assessments. The algorithm of this method can be described as follows (Durmić et al., 2020; Đalić et al., 2020), as shown in Figure 1.

Figure 1
FUCOM algorithm

Algorithm: FUCOM

Input: Expert pairwise comparison of criteria
Output: Optimal values of the weight coefficients of criteria/sub-criteria

Step 1: Expert ranking of criteria/sub-criteria.
Step 2: Determining the vectors of the comparative significance of evaluation criteria.
Step 3: Defining the restrictions of a non-linear optimization model.
Restriction 1: The ratio of the weight coefficients of criteria is equal to the comparative significance among the observed criteria, i.e. $w_k / w_{k+1} = \varphi_{k/(k+1)}$.
Restriction 2: The values of weight coefficients should satisfy the condition of mathematical transitivity, i.e. $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$.
Step 4: Defining a model for determining the final values of the weight coefficients of evaluation criteria:

$$\min \chi$$
$$s.t.$$
$$\left| \frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \right| \leq \chi, \ \forall j$$
$$\left| \frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \leq \chi, \ \forall j$$
$$\sum_{j=1}^{n} w_j = 1$$
$$w_j \geq 0, \ \forall j$$

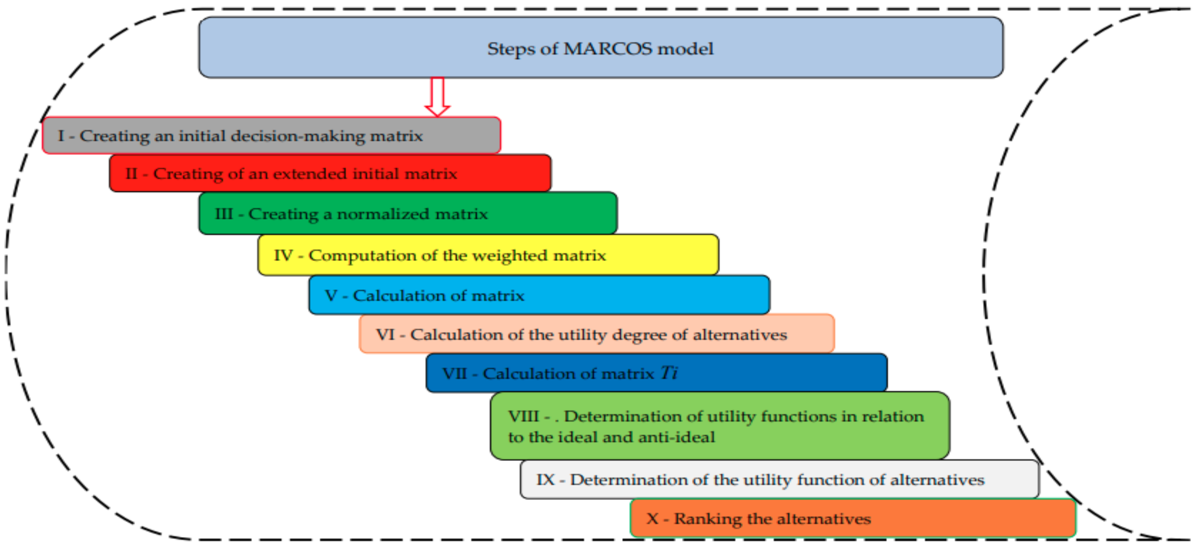
Step 5: Calculating the final values of evaluation criteria/sub-criteria $(w_1, w_2, ..., w_n)^T$.

Source: (Stević et al., 2023)

MARCOS method

The MARCOS method (Stević et al., 2020) is an MCDM method for ranking potential solutions. Represents very popular methods based on defining the relationship between ideal and anti-ideal solutions. MARCOS method contains the following steps, shown in Figure 2.

Figure 2.
MARCOS algorithm

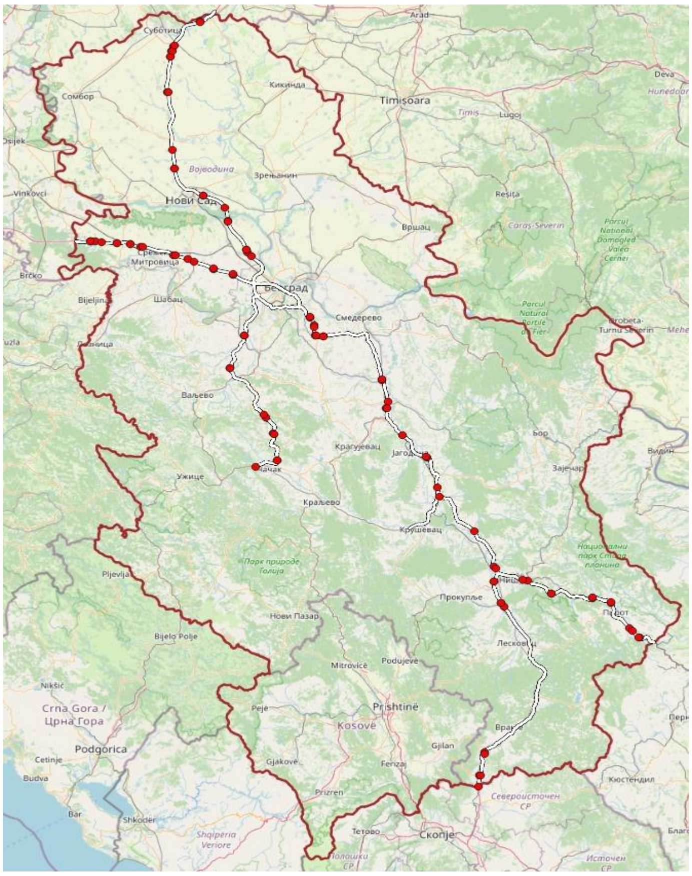


Source: (Stević et al., 2023)

Results

This study is part of a project related to selecting locations for parking lots for vehicles carrying dangerous goods. The research has been conducted in the territory of the Republic of Serbia as an important step toward achieving sustainable goals and protecting the environment. The whole project considered the highway network shown in Figure 3, whereas this paper presents an example of selecting locations for only one road section in one direction (3a - section D3 on the road direction Horgoš - Belgrade border crossing, length 210 km, direction Belgrade).

Figure 3
Highway network in the Republic Serbia



Source: (Smiljanić et al. 2024)

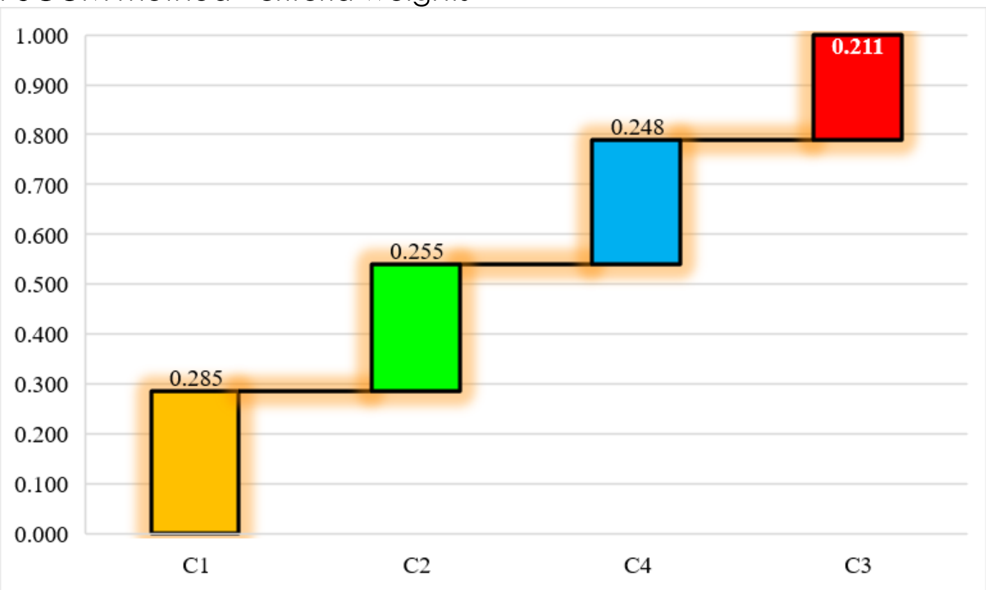
For the mentioned project, the following criteria have been defined:

- C1 - distance from inhabited areas; C2 - environmental protection and distance from watercourses; C3 - properties (industrial, communal, public, and other facilities); and C4 - available infrastructure. For road section 3a the following potential locations are considered:
- A1 - existing parking lot "Horgoš" - direction towards Belgrade, geographic coordinates: N 46.141037, E 19.904305;
- A2 - expansion and arrangement of the parking lot at the "Subotica" toll station - direction towards Belgrade, geographic coordinates: N 46.020342, E 19.733309;
- A3 - existing parking lot "Bikovo" - direction towards Belgrade, geographic coordinates: N 45.997220, E 19.720565;

- A4 - arrangement of the parking lot at the fuel supply station "EKO", direction towards Belgrade, geographical coordinates: N 45.966816, E 19.709897;
- A5 - arrangement of the parking lot at the fuel supply station "OMV", direction towards Belgrade, geographical coordinates: N 45.791912, E 19.694003;
- A6 - existing parking lot "Mandić" - direction towards Belgrade, geographic coordinates: N 45.507824, E 19.725166;
- A7 - existing parking lot "Sirig" - direction towards Belgrade, geographic coordinates: N 45.411754, E 19.736421;
- A8 - expansion and arrangement of the parking lot at the "Gazprom petrol" toll station - direction towards Belgrade, geographic coordinates: N 45.275617, E 19.922316;
- A9 - existing independent parking lot "Kovilj" - direction towards Belgrade, geographic coordinates: N 45.216111, E 20.063435;
- A10 - expansion and arrangement of the parking lot at the fuel supply station "OMV" - direction towards Belgrade, geographic coordinates: N 45.149095, E 20.082602;
- A11 - arrangement of the parking lot at the fuel supply station "Petrol - Stara Pazova", direction towards Belgrade, geographic coordinates: N 44.994081, E 20.208520;
- A12 - expansion and arrangement of the parking lot at the "Stara Pazova" toll station - direction towards Belgrade, geographic coordinates: N 45.005311, E 20.201381

After the creation of the MCDM model with four criteria and 12 alternatives, the first step should be to apply the FUCOM method for determining criteria weights (Figure 4) and MARCOS for the selection of the most suitable locations (Table 1).

Figure 4
FUCOM method - criteria weights



Source: Author's illustration

Figure 4 shows the calculated criterion weights using the FUCOM method: C1 = 0.285, C2 = 0.255, C3 = 0.211, and C4 = 0.248.

Table 1
Final results of the integrated FUCOOM-MARCOS model

	Si	Ki-	Ki+	fK-	fK+	Ki	Rank
AAI	0.301						
A1	0.651	2.160	0.651	0.232	0.768	0.608	7
A2	0.569	1.887	0.569	0.232	0.768	0.532	10
A3	0.915	3.037	0.915	0.232	0.768	0.856	1
A4	0.538	1.786	0.538	0.232	0.768	0.503	11
A5	0.635	2.106	0.635	0.232	0.768	0.593	8
A6	0.777	2.578	0.777	0.232	0.768	0.726	4
A7	0.783	2.599	0.783	0.232	0.768	0.732	3
A8	0.388	1.289	0.388	0.232	0.768	0.363	12
A9	0.656	2.175	0.656	0.232	0.768	0.613	6
A10	0.767	2.546	0.767	0.232	0.768	0.717	5
A11	0.621	2.061	0.621	0.232	0.768	0.581	9
A12	0.815	2.703	0.815	0.232	0.768	0.762	2
AI	1.000		1.000				

Source: Author's calculation

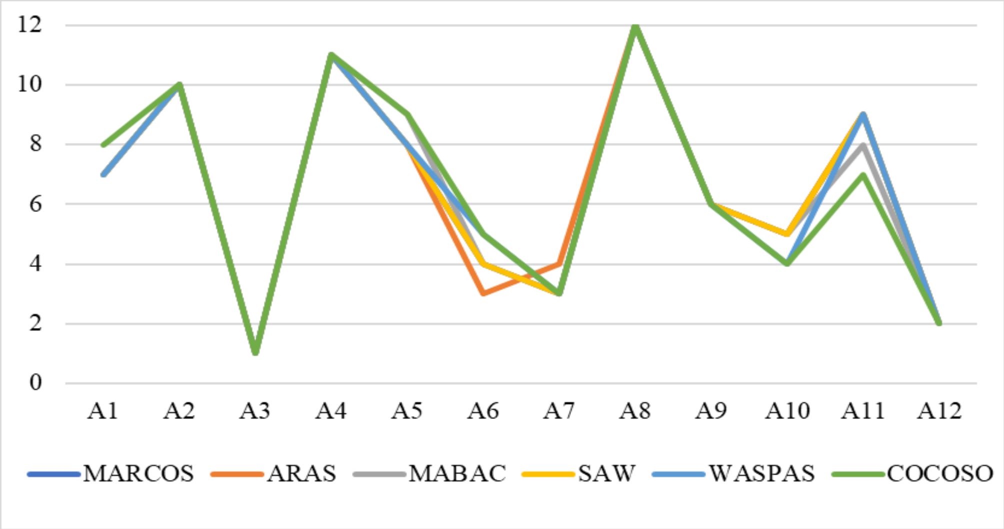
Depending on the length of the road section, select two or three locations per direction. In this case, because the length is 210 km, the three following locations have been selected:

- A3 - existing parking lot "Bikovo" - direction towards Belgrade, geographic coordinates: N 45.997220, E 19.720565;
- A7 - existing parking lot "Sirig" - direction towards Belgrade, geographic coordinates: N 45.411754, E 19.736421;
- A12 - expansion and arrangement of the parking lot at the "Stara Pazova" toll station - direction towards Belgrade, geographic coordinates: N 45.005311, E 20.201381

Check analysis and Discussion

This section presents a comparative analysis, a sensitivity analysis, and the calculation of correlation coefficients for the ranks of locations in the sensitivity analysis. The comparative analysis has been performed with five more MCDM methods: ARAS (Zavadskas & Turskis, 2010), MABAC (Torkayesh et al., 2023), SAW (Amalia & Alita, 2023), WASPAS (Zavadskas et al., 2012), CoCoSo (Yazdani et al., 2019).

Figure 5
Results of comparative analysis

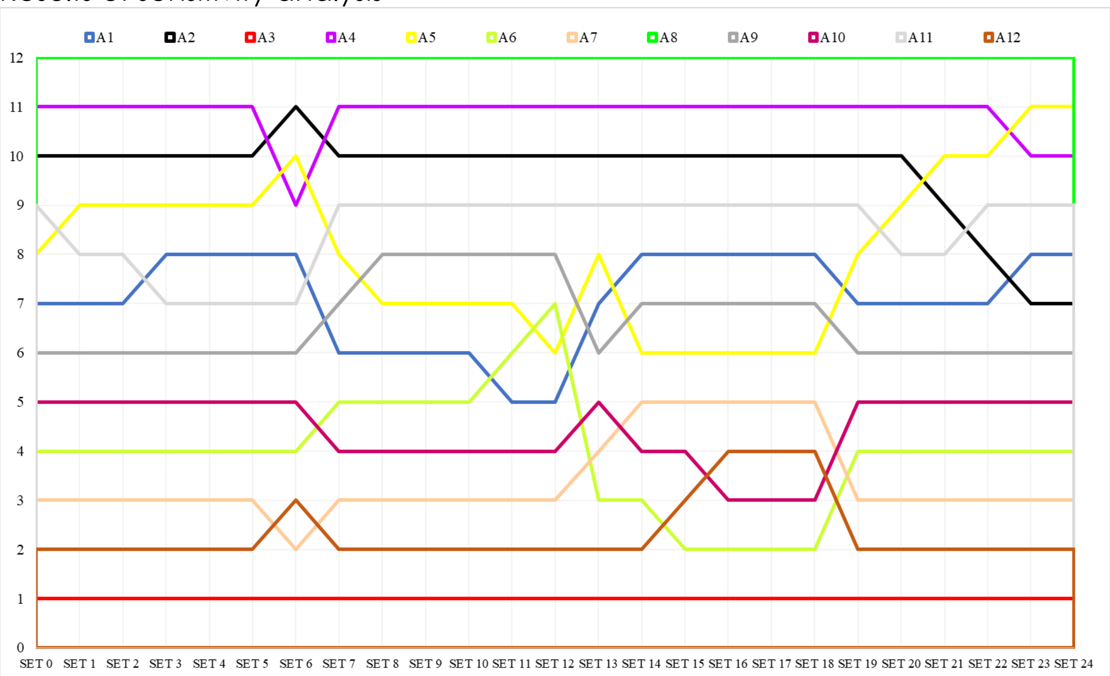


Source: Author's illustration

Results from the comparative analysis confirm that the selected three locations are valid. Locations A3 and A12 maintained their positions throughout the comparative analysis. Location A7, with the ARAS method, rotates the place with location A6 only. The most significant change in this analysis is between MARCOS and CoCoSo methods for location A11 when changing position from eight to seven.

The second part of this analysis presents changing criteria weights across 24 scenarios in which the significance of the criteria ranges from 15% to 90%. For example, in the first scenario, the weight of C1 was reduced by 15%, while in the sixth scenario, the weight of the same criterion was reduced by 90%. In Figure 5, all changes in the ranks of locations are influenced by modeling new criteria weights represented.

Figure 5
Results of sensitivity analysis

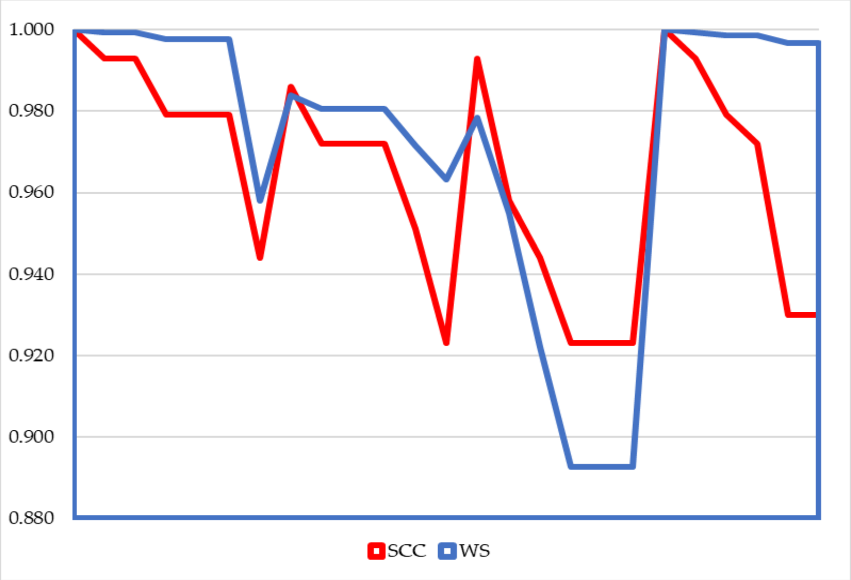


Source: Author's illustration

Sensitivity analysis shows that the obtained results are sensitive to reducing the significance of some criteria. The best location, A3, kept its first position in all scenarios, while the others changed by 1, 2, or 3 places, including the second- and third-best locations, A7 and A12, respectively. In the sixth scenario, when C1 kept only 10% of its own value, A7 is the second-best alternative instead of the third-best as in the initial scenario. The third criterion, C3, has the greatest influence on location A7, finishing third in all scenarios S13-S18. A similar situation is with A12 in scenarios S15-S18.

Figure 6 shows the computed correlation coefficients from a sensitivity analysis. Two coefficients are computed: SCC (Mousavi et al., 2024) and WS (Salabun & Urbaniak, 2020).

Figure 6
Correlation coefficients for ranks in sensitivity analysis



Source: Author's illustration

The calculated coefficients show a very high correlation between ranks in the sensitivity analysis, with average SCC = 0.964 and WS = 0.973. The lowest correlation is in scenarios S16-S18 and WS = 0.893.

Conclusion

In this paper, an integrated MCDM model for selecting three suitable locations from 12 considered at a road section of the highway network has been applied. Locations represent places for parking vehicles with dangerous goods. The total number of potential locations on the highway network in the Republic of Serbia is 92, divided into six sections with two directions. The entire project aims to define scenarios for the entire network to enhance network security. This paper has considered the application of the FUCOM-MARCOS model and obtained results show that locations marked as A3, A7, and A12 are the best in this considered road section.

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