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A novel hybrid fuzzy model for selection of parking lots for vehicles with dangerous goods

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A R T I C L E I N F O

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Dangerous goods
Parking lots
Fuzzy pivot pair-wise relative criteria importance assessment
Fuzzy measurement of alternatives and ranking according to the compromise solution
Z numbers

A B S T R A C T

With increasing participation of hazardous materials in supply chains, there is a need for greater attention in the transport subsystem and all activities that are directly or indirectly related to this field. One of the direct activities, which has not been sufficiently investigated, relates to the locations for parking of freight vehicles with dangerous goods. In the territory of Serbia, where the research has been conducted, there are no prescribed locations of this type. Thus, in order to overcome that gap, a novel multi-criteria decision-making model based on Z numbers has been defined. The purpose of developing this model, which consists of fuzzy Pivot Pair-wise Relative Criteria Importance Assessment and fuzzy Measurement of Alternatives and Ranking according to the Compromise Solution methods and Z numbers, is to define a set of the required 28 locations that are most suitable for parking vehicles with dangerous goods out of a potential set of 92 locations. Fuzzy Pivot Pair-wise Relative Criteria Importance Assessment with Z numbers is defined for the first time in the literature and is used to determine weighting coefficients, while the Fuzzy Measurement of Alternatives and Ranking according to the Compromise Solution with Z numbers is applied for the ranking of locations. It is important to emphasize that a total of 12 evaluation models have been formed in order to segmentally determine suitable locations from the aspect of six highway sections. The results represent the selection of the most suitable locations in relation to the length of the observed sections and directions, so a final set of 28 locations was formed. Verification of the proposed model was carried out through sensitivity analysis, comparative analysis, and calculation of correlation coefficients. Further research involves the formation of different scenarios that will consist of several locations out of the 28 selected, taking into account the criterion of their least mutual distance. It is necessary to form scenarios for both directions of all highway sections, and make a decision recommending to competent institutions the exact number and locations for parking lots for vehicles with dangerous goods.

1. Introduction

Dangerous goods are an integral part of a technically highly developed industrial society. It is used for various purposes, as a raw material, semi-finished product, or finished product to use as a tool for performing daily tasks. Modern civilization is facing a serious problem that is a product of industry, which is the use, transport, and storage of dangerous goods. Bearing in mind the importance of this problem and possible omissions during the transport, storage, and handling of these substances, it is important to respect certain procedures during various activities in the supply chains of dangerous goods. So, on the one hand, dangerous goods represent a risk for humans and the environment, and on the other hand, they are a necessity in the modern world, so manipulation and transport, although very risky, are present and inevitable every day. Dangerous goods are defined as articles or substances the carriage of which is prohibited or permitted if it is carried out under the conditions specified by the Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR, 2023). When it comes to

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road transport, it is estimated that the transport of dangerous goods takes over 4% of the total volume of this mode of transport. In view of this fact, the risk of accidents also emerges, so the risk assessment in the transport of dangerous goods has resulted in the definition of norms and regulations by competent authorities when carrying out transport activities. The primary purpose and goal of organizing individual actions in the field of transport is safety and protection of people, properties and the environment, as well as performing preventive engineering.

1.1. Motivation for research

Transport of dangerous goods by road is one of the best regulated areas (Sremac and Matijašević, 2021; Vojinović et al., 2021). However, within it, one of the fields that needs to be regulated in the transport of dangerous goods is the parking of vehicles that transport this type of goods, that is, the supervision of those vehicles in parking lots and rest areas. The requirements for the supervision of vehicles transporting dangerous goods are defined in chapters 8.4 and 8.5 of ADR (2023), but it is necessary for competent state authorities to regulate this area more precisely by national legislation and regulations, certainly corresponding to their own conditions of using this mode of transport and parking requirements. The FACTS Dangerous Goods Accident Database contains more than 26,500 descriptions of accidents. A search of data on accidents in parking lots (with road transport as the activity and a parking lot as the location) yielded a total of 95 accidents in the period from 1976 to 2014 (www.factsonline.nl/browse-chemical-accidents-in-database). The largest number of accidents was recorded in the USA (27), followed by the Netherlands (24), Australia (10), Germany (8) and Great Britain (7). In three accidents there were fatalities and injuries, in 28 only injuries, and in 31 accidents there were no fatalities or injuries, but material damage was caused. Human responsibility was identified in 14 accidents, technical error was identified in 13 accidents, a terrorist act was committed in seven accidents (transportation of fuel), management error was identified in five accidents and natural causes were identified in two, while the causes of accident occurrence are unknown for 54 accidents. Taking into account the above, the motive for this research emerges, with a view to manage the transport of dangerous goods as noted in (Lazić et al., 2022) and the risk it entails in a preventive way (by selecting the most suitable locations and monitoring).

1.2. Subject and aims of research

In the modern conditions for the functioning of the transport chain of dangerous goods, in order to protect the environment, the lives of people involved in the processes of this system, and to achieve its greater efficiency, it is necessary to constantly measure and monitor the performance of the transport chain of dangerous goods. In this way, it is possible to achieve a proactive way of management, which includes preventive engineering and management of potential accident situations and reducing risks to the lowest possible level. Considering the fact that the modern transport market of dangerous goods is exposed to constant changes and that increasingly strict social, technological, economic, logistic and other requirements are being set, it is necessary to point out that it is a great challenge to achieve the sustainability of this system.

The subject of the research is the dangerous goods transport system including all activities and processes within the system, with a strong emphasis on forming an adequate base of potential locations for parking vehicles with dangerous goods, determining suitable locations, and performing their evaluation based on a set of significant input parameters that have been defined. The subject of the research can greatly influence the overall transport chain of dangerous goods, the safety and efficiency of the flows that take place in it. Therefore, the formation of a network with suitable locations for parking vehicles with dangerous goods can have an exceptional importance for the overall social and business system, which will be proven through the very implementation of the model in the future, so from that aspect it is justified as a subject of the research.

The main aim of the research involves the possibility of improving the safety and efficiency of the flows of dangerous goods through the definition and formation of a network of suitable locations for parking vehicles with dangerous goods. The possibility of improvement, that is, the aim of this paper, is achieved by research in a real system and time, which includes monitoring and analysis of all potential locations on the IA road network, applying current professional and scientific achievements in the field. In addition, the application of multi-criteria decision-making integrated with the theory of uncertainty can contribute to the fulfillment of the aim which has been set.

1.3. Scientific and professional contributions

The contributions of this paper can be presented through the following facts:

- An original MCDM model, F-PIPRECIA-Z-F-MARCOS-Z which involves the integration of various methods with Z numbers, was developed.
- This model has been presented for the first time in the literature, including the extension of the fuzzy PIPRECIA method with Z numbers, which makes it possible to determine the weights of the criteria with greater precision.
- The contribution of the development of this model is in the fact that it can be implemented throughout different areas. From the social and professional aspect, the contribution of the model can be reflected through its adaptation to specific conditions that prevail in real time, whereby, depending on their own social, technological, ecological and economic needs and requirements, competent personnel can model the results. By taking into account the aforementioned, the personnel determine the significance of the criteria on the basis of which the evaluation is performed or the input parameters are changed.
- The model developed as part of this research can serve decision-makers at competent authorities to define the number and exact layout of parking lots for vehicles with dangerous goods that have the best characteristics.

1.4. The structure of the paper

In addition to the previously defined elements, motivation, subject and aim of the research, contribution of the study, this paper includes the following sections. Section 2 presents the background divided into three parts: the selection of parking lots using different approaches, a review of the application of MCDM methods in the field of transport and logistics of dangerous goods, and research gaps. Section 3 presents a diagram of the research flow and a detailed explanation of the development of the F-PIPRECIA-Z-F-MARCOS-Z model. Section 4 is essential and refers to the description of the creation of the model, data collection, evaluation by experts, the application of the developed model and presentation of the most important results. Section 5 presents the verification tests, and the last section includes concluding remarks with implications for future research.

2. Background

Through this section of the paper, all essential elements regarding the research area have been processed, including the review of various studies and approaches that define the requirements, criteria for the selection of parking lots for vehicles with dangerous goods and the need to form a network of the locations, etc. Also, different forms of the application of MCDM methods in the research field are given.

2.1. Selection of parking lots using different approaches

Considering the complexity of the research area, the fact is that there are different procedures for approaching this problem, starting from location problems and vehicle routing problems, to the guidelines recommended to the competent authorities for planning and designing parking areas and monitoring vehicles for the transport of dangerous goods. Many studies take into account a large number of factors that directly or indirectly have an impact on the carriage of dangerous goods. When it comes to the supervision of vehicles for the transport of dangerous goods, certain studies were carried out, and they are briefly elaborated below.

Caro-Vela et al. (2013) conducted research in the territory of Spain with the aim of considering the criteria for determining the parking locations for vehicles transporting dangerous goods, and they refer to: the coverage of the carriers' demand, the services provided at the rest areas, the social risk associated to this type of area. The authors tried to develop an adequate model consisting of the application of the DEA method using the available data related to the transport of dangerous goods and potential locations in Spain. Quantitative and qualitative shortages were observed in terms of safety of existing parking areas. The authors also state that there is a need to develop a model that will enable institutions responsible for planning and managing service areas to select a network of these areas that can be adjusted according to objective criteria to meet other requirements of dangerous goods carriers. The paper considered a total of 89 potential locations that meet the conditions, while adequate data was available for 66 locations. The results obtained show that the selected 11 zones, in addition to the existing ones, would not fully cover the demand, because certain areas would still be uncovered. Caro and Paralera (2011) in their research try to describe the necessity for resorts that are adapted for the transport of dangerous goods, using a location model supported by a GIS system. The aim of this study is to analyze the needs for a network of locations where parking will be provided for vehicles with dangerous goods. The aim of the study by Betkier et al. (2021) is the creation of a model based on the vehicle routing problem, with which it is necessary to determine the priority route from the loading point to the unloading point for vehicles that require specific parking conditions. The following aspects were also taken into account: availability and space of the parking lot, drivers' working hours, traffic flow and parking lot equipment, which are considered necessary to define the essence of the problem. In the paper, the authors Caro et al. (2015) designed an efficient algorithm for determining the location of parking areas for vehicles transporting dangerous goods in the European road network. The aim was to determine the minimum number of parking areas in compliance with positive regulations.

2.2. Studies with MCDM methods in the field of dangerous goods

One of the most common decision-making methodologies is MCDM, which has been applied in various areas of transport (Badi and Bouraima, 2023; Jusufbašić and Stević, 2023; Stanimirović et al., 2023) or logistics (Švadlenka et al., 2023; Dabić-Miletić and Raković, 2023; Puška et al., 2023). However, when it comes to the field of transport of dangerous goods or systems related to this category of goods, there is much less research. Therefore, a certain number of authors who base their research in the field of dangerous goods transport on the application of these methods in different forms are shown below, which is elaborated in Table 1.

Based on the research papers presented, it can be concluded that as time passes, MCDM methods have a greater application in the field of transport of dangerous goods, but not even as similar as some other fields. The problems of routing, selection of 3 PL providers, and assessment of risk factors are most often solved. In addition to the transport of dangerous goods, MCDM methods can also be applied for the selection of warehouses for dangerous goods (Kabak and Keskin, 2018) as part of the model, because in the paper they are integrated with GIS or used as independent ones. Also, they are successfully applied for the selection of the location for the treatment of hazardous waste and their disposal, as was done in the paper (Feng, 2022).

Table 1
A brief overview of the studies with MCDM methods in the field of dangerous goods transport.

Reference	Methods applied	Purpose
Monprapussorn et al. (2011)	AHP and GIS	Evaluation of routes in TDG
Özkan and Eroğlu (2014)	Fuzzy DEMATEL and Fuzzy TOPSIS	Selecting 3 PL providers
Pamučar et al. (2019)	LNN WASPAS	Evaluation and ranking of advisors in TDG
Sremac et al. (2018)	Rough SWARA-WASPAS and Rough Dombi operator	Selecting 3 PL providers for chemical enterprises
Kanj and Abi-Char (2019)	Fuzzy TOPSIS	Evaluation of the risk level, travel duration and costs within it
Li et al. (2019)	QFD, Fuzzy AHP, Fuzzy FMEA, nonlinear goal programming	Risk management of hazardous materials
Gul et al. (2019)	Fuzzy AHP	Risk assessment of routes in oil transportation
Hervás-Peralta et al. (2020)	Delphi and AHP	Spatial planning of terminals with dangerous goods
Huang et al. (2020)	revised fuzzy AHP	Assessment of the safety level of operational processes in TDG in air transport
Ayyildiz and Taskin Gumus (2021)	Delphi and Pythagorean fuzzy AHP	Defining key risk factors for operations in TDG
Vojinović et al. (2021)	IMF SWARA-Rough MARCOS	Ranking of 11 companies which deals with TDG
Derse et al. (2022)	FTA, TOPSIS and DEMATEL	Risk assessment in each phase of TDG of different modes of transport
Yilmaz and Verter (2022)	AHP, TOPSIS and GIS	Finding optimal routes
Simić et al. (2023)	ITARA and EDAS based type-2 neutrosophic model	Selecting a sustainable route for TDG
Tseng and Pilcher (2023)	Fuzzy AHP	A safety Assessment model for handling dangerous goods

2.3. Research gaps

Initial research regarding the situation in the field shows that there are very few studies in the world regarding the definition of parking lots and locations for parking vehicles with dangerous goods, and that there is no single procedure, but it is necessary to adjust the parameters of the model to specific conditions of the transport of dangerous goods. It is especially evident that there is a gap of this kind of research in the Republic of Serbia, which imposes the need to create an imagined model. Considering all the above, it sets as a requirement of great importance the formation of a model for the evaluation of potential locations for parking vehicles with dangerous goods, and the formation of network scenarios of adequate locations on the IA road network.

3. Research flow and methods

3.1. Research flow and dynamics

Fig. 1 shows the research flow and applied methodology, which is explained throughout a total of five phases: theoretical research, data collection, development of a novel MCDM model based on Z numbers in order to achieve the research aim, verification tests and conclusions with further research. The first phase contains two steps, the second phase three steps. The main stage of the paper is presented through four steps, while the next stage contains four tests in total. The last stage is related

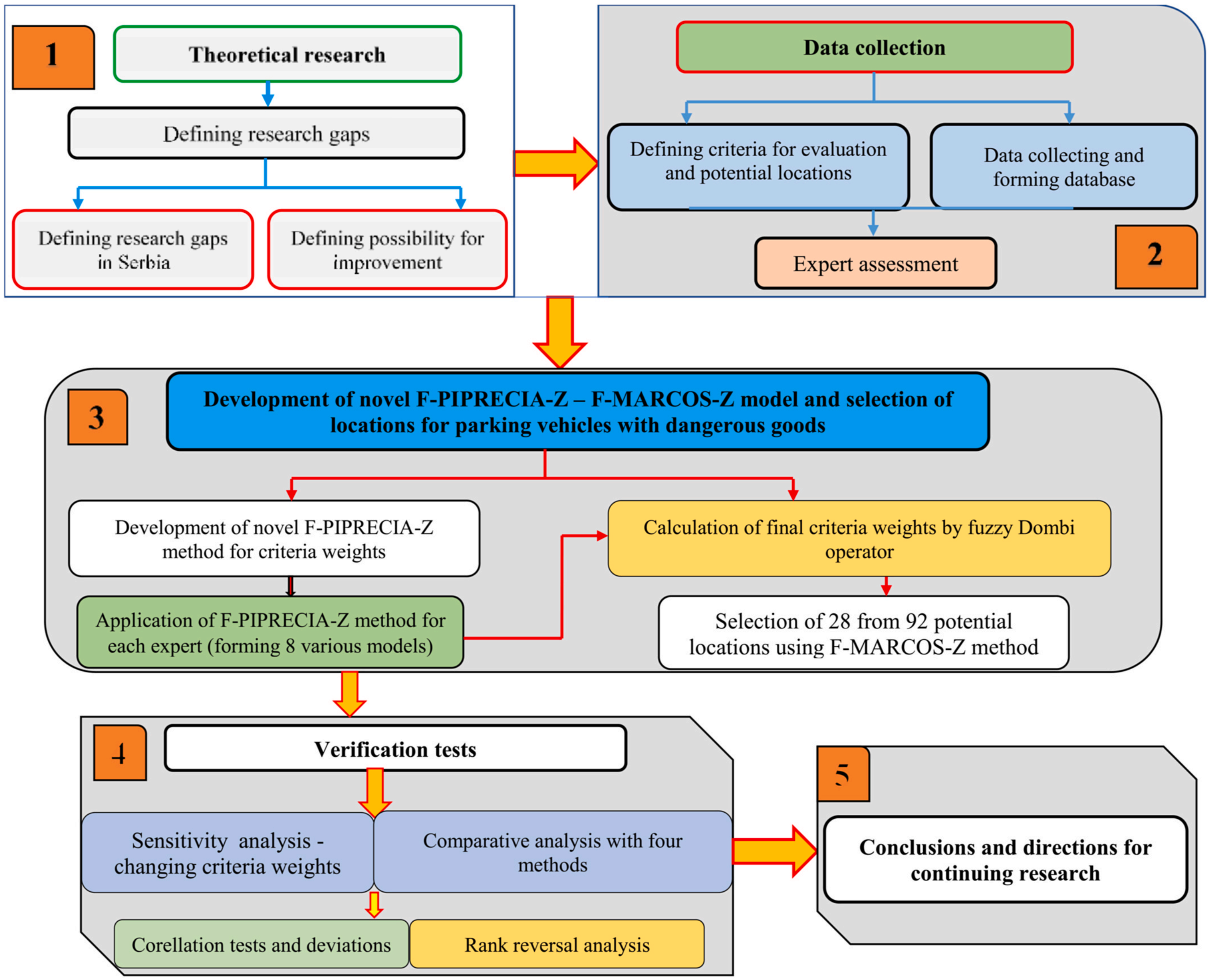

Fig. 1. Research flow diagram.

to short discussions and guidelines for continuing research.

In Phase 1, theoretical research is carried on the basis of a review of relevant literature, identification of potential gaps in the area that is the subject of research and definition of areas of possible improvement, especially when it comes to the territory of the Republic of Serbia where the research has been conducted. Phase 2 involves defining input parameters for forming an adequate model, then defining potential locations, collecting data and forming a database. In order to create a functional model, it is necessary to provide high-quality data that will ensure the consistency of the model and enable its practical application. Within this phase, experts are included to assess the importance of a set of criteria, and potential locations out of which it is necessary to define those that will enter the model and form a parking lot network for vehicles with dangerous goods. The experts assessed criteria and locations based on existing appropriate linguistic scales. In Phase 3, the original model based on multi-criteria decision-making methods and integration with fuzzy logic theory has been created. Different approaches are integrated into a unique model that should provide adequate support when making decisions about the required number of parking spaces for vehicles with dangerous goods and their arrangement within the IA road network of the Republic of Serbia. This stage represented the core of the study with clearly explained novelties and contributions. Furthermore, in the next phase, verification tests are created. Within this phase, a comparative analysis with existing methods are performed in order to verify the model developed, and the focus is on changing the significance of input parameters, which are very important in every decision-making process, and statistical tests of correlation and deviation from the initial model are calculated. Also, rank reversal analysis has been performed to check the robustness of the proposed model. Finally, concluding considerations, which include the possibility of applying the obtained results and determination of the guidelines for further research in the field, are elaborated.

3.2. Z numbers

Z numbers denote two fuzzy numbers, connected in a specific way. The concept of Z numbers was defined by Zadeh (2011). Details related to application of this numbers has been represented in the study (Kang et al., 2012). These numbers were used in many studies (Bozanic et al., 2020; Stević et al., 2022; Jovanović et al., 2023; Haseli et al., 2023) and represent an ordered pair of fuzzy numbers $Z=(\widetilde{A}, \widetilde{B})$. The fuzzy number $\widetilde{A}$ is the first component that represents the fuzzy limit of a certain variable X, while the fuzzy number $\widetilde{B}$ is the second component that represents the probability and reliability of the first component ($\widetilde{A}$). Fig. 2 presents the form of Z numbers with triangular fuzzy numbers by

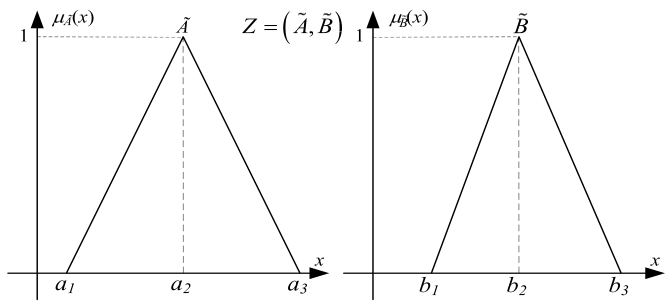

Fig. 2. Z numbers (Kang et al., 2012).

Zadeh (2011), and Table 2 shows the probability, that is, TFN $\widetilde{B}$.

The general notation of triangular Z numbers can be shown as:

$$\widetilde{Z} = \{(a_1, a_2, a_3; w_{\widetilde{A}}), (b_1, b_2, b_3; w_{\widetilde{B}})\} \tag{1}$$

where the values $w_{\widetilde{A}}$ and $w_{\widetilde{B}}$ are weighting factors of the fuzzy number $\widetilde{A}$ related to $\widetilde{B}$, which for the initial Z number is defined by most authors as $w_{\widetilde{A}} = w_{\widetilde{B}} = 1$, $w_{\widetilde{A}}, w_{\widetilde{B}} \in [0,1]$, ($w_{\widetilde{A}}$ represents the value of the generalized fuzzy number and ranges in the interval $0 \leq w_{\widetilde{A}} \leq 1$) (Stević et al., 2022). With the proof presented, the Z number is transformed into a classical fuzzy number as follows:

Transforming the second part ($\widetilde{B}$) into a crisp number using the centroid method:

$$\alpha = \frac{a_1 + a_2 + a_3}{3} \tag{2}$$

Adding the weight of the second part ($\widetilde{B}$) to the first component ($\widetilde{A}$), the weighted Z number is obtained, and it is shown below:

$$\widetilde{Z}^{\alpha} = \{\langle x, \mu_{\widetilde{A}^{\alpha}}(x)\rangle | \mu_{\widetilde{A}^{\alpha}}(x) = \alpha \mu_{\widetilde{A}}(x)\} \tag{3}$$

which is given as:

$$\widetilde{Z}^{\alpha} = (a_1, a_2, a_3; \alpha) \tag{4}$$

Transforming the weighted Z into a regular fuzzy number. A regular fuzzy set is shown as follows:

$$\widetilde{Z}^{'} = \sqrt{\alpha} * \widetilde{A} = \left(\sqrt{\alpha} * a_1, \sqrt{\alpha} * a_2, \sqrt{\alpha} * a_3\right) \tag{5}$$

3.3. Fuzzy PIPRECIA method based on Z numbers

The advantage of Z numbers was elaborated in many studies (Chatterjee and Kar, 2018; Peng et al., 2022; Gai et al., 2023). Our decision to extend this method with Z numbers lies in that is very important for our study to include the probability of the assessed elements of the MCDM model.

The main goal of creating the extended F-PPRECIA method is the integration of the advantages of this method, which enables precise weights of criteria in group decision-making, and the advantages of Z numbers. The greater the number of experts involved in the research, the greater the importance of this approach. The original fuzzy PIPRECIA method was developed by Stević et al. (2018) and since then it has been exploited in many fields (Attri and Mishra, 2022; Xu et al., 2023; Mishra et al., 2023). The algorithm of the F-PIPRECIA-Z method is shown below.

Table 2
The second component of the Z number.

Possibility	TFN $\widetilde{B}$
Very small (VS)	(0, 0, 0.2)
Small (S)	(0.1, 0.25, 0.4)
Medium (M)	(0.3, 0.5, 0.7)
High (H)	(0.55, 0.75, 0.95)
Very high (VH)	(0.8, 1, 1)

Step 1. Based on research requirements, create a set of elements that represent the criteria and a group of experts for their mutual assessment.

Step 2. Formation of the initial matrix, which implies that each expert individually determines the mutual comparison of criteria using the scales defined in (Stević et al., 2018), and the probability of occurrence of the Z number according to Table 2. It is important to emphasize that it is determined how much the criterion C_j is more or less important than the previous one, and the evaluation starts from the second criterion.

$$\widetilde{s_j^r} = \begin{cases} > \widetilde{1} & if \quad C_j > C_{j-1} \\ = \widetilde{1} & if \quad C_j = C_{j-1} \\ < \widetilde{1} & if \quad C_j < C_{j-1} \end{cases} \tag{6}$$

$\widetilde{s_j^r}$ - rating by the expert r.

In order to create the matrix $\widetilde{s_j^r}$ shown in Eq. (6), it is necessary to transform the Z numbers into TFNs according to the previously defined rules.

Step 3. Depending on decision-making requirements, make a decision on the method of further calculation. There are two options. The first option involves collecting all expert ratings and averaging them into a single initial matrix. The second option involves applying the F-PIPRECIA-Z method for each expert separately, and then their averaging. So, if we have r experts participating in the process of evaluating the importance of criteria, we will also have r models.

Step 4. Determination of the coefficient $\widetilde{k_j}$.

$$\widetilde{k_j} = \begin{cases} = \widetilde{1} & if \quad j = 1 \\ 2 - \widetilde{s_j} & if \quad j > 1 \end{cases} \tag{7}$$

Step 5. Determination of the fuzzy weight $\widetilde{q_j}$.

$$\widetilde{q_j} = \begin{cases} = \widetilde{1} & if \quad j = 1 \\ \dfrac{\widetilde{q_j}}{\widetilde{k_j}} & if \quad j > 1 \end{cases} \tag{8}$$

Step 6. Determination of the relative weight of the criterion $\widetilde{w_j}$.

$$\widetilde{w_j} = \frac{\widetilde{q_j}}{\sum_{j=1}^{n} \widetilde{q_j}} \tag{9}$$

The next part of the algorithm involves the application of the inverse F-PIPRECIA-Z method.

Step 7. Perform the evaluation applying the previously defined scales, but this time starting from the penultimate criterion.

$$\widetilde{s_j^{r'}} = \begin{cases} > \widetilde{1} & if \quad C_j > C_{j+1} \\ = \widetilde{1} & if \quad C_j = C_{j+1} \\ < \widetilde{1} & if \quad C_j < C_{j+1} \end{cases} \tag{10}$$

Step 8. Determination of the coefficient $\widetilde{k_j}'$.

$$\widetilde{k_j}' = \begin{cases} = \widetilde{1} & if \quad j = n \\ 2 - \widetilde{s_j}' & if \quad j > n \end{cases} \tag{11}$$

n – number of criteria.

Step 9. Determination of the fuzzy weight $\widetilde{q_j}'$.

$$\widetilde{q}_j^{'} = \begin{cases} = \widetilde{1} & if \quad j = n \\ \dfrac{\widetilde{q_{j+1}}^{'}}{\widetilde{k}_j^{'}} & if \quad j > n \end{cases} \tag{12}$$

Step 10. Determination of the relative weight of the criterion $\widetilde{w}_j^{'}$.

$$\widetilde{w}_j^{'} = \frac{\widetilde{q}_j^{'}}{\sum_{j=1}^{n} \widetilde{q}_j^{'}} \tag{13}$$

Step 11. In order to determine the final criteria weights, first it is necessary to apply Eq. (14).

$$\widetilde{w}_j^{''} = \frac{1}{2}\left(\widetilde{w}_j + \widetilde{w}_j^{'}\right) \tag{14}$$

Step 12. Test the obtained results using the Spearman and Pearson correlation coefficients.

3.4. Fuzzy Dombi aggregator

The Fuzzy Dombi aggregator is represented by Eqs. (16) and (17) (Saha et al., 2022; Jana and Pal, 2023). This operator has been widely applied for the aggregation of values in many studies dealing with MCDM methodology. The Dombi's operations carry the advantage of more pliability and reliability due to the existence of their operational parameters (Riaz et al., 2021).

$$FDO(\widetilde{\wp}) = \left(\wp_j^l, \wp_j^m, \wp_j^u\right) = \begin{cases} \wp_j^l = \dfrac{\sum_{j=1}^{n}\left(\wp_j^l\right)}{1 + \left\{\sum_{j=1}^{n} w_j \left(\dfrac{1-f\left(\wp_j^l\right)}{f\left(\wp_j^l\right)}\right)^{\rho}\right\}^{1/\rho}} \\ \wp_{ij}^m = \dfrac{\sum_{j=1}^{n}\left(\wp_j^m\right)}{1 + \left\{\sum_{j=1}^{n} w_j \left(\dfrac{1-f\left(\wp_j^m\right)}{f\left(\wp_j^m\right)}\right)^{\rho}\right\}^{1/\rho}} \\ \wp_{ij}^u = \dfrac{\sum_{j=1}^{n}\left(\wp_j^u\right)}{1 + \left\{\sum_{j=1}^{n} w_j \left(\dfrac{1-f\left(\wp_j^u\right)}{f\left(\wp_j^u\right)}\right)^{\rho}\right\}^{1/\rho}} \end{cases} \tag{16}$$

w_j - weights of r experts, while $p \geq 0$ is a positive number, $\wp_j^l$- the lower value of TFN, $\wp_j^m$- the mean value of TFN and $\wp_j^u$- the upper value of TFN.

$$f\left(\wp_j^l, \wp_j^m, \wp_j^u\right) = \begin{cases} f\left(\wp_j^l\right) = \dfrac{\left(\wp_j^l\right)}{\sum_{j=1}^{n}\left(\wp_j^l\right)} \\ f\left(\wp_j^m\right) = \dfrac{\left(\wp_j^m\right)}{\sum_{j=1}^{n}\left(\wp_j^m\right)} \\ f\left(\wp_j^u\right) = \dfrac{\left(\wp_j^u\right)}{\sum_{j=1}^{n}\left(\wp_j^u\right)} \end{cases} \tag{17}$$

3.5. Fuzzy MARCOS method based on Z numbers

The MARCOS method basically includes finding a solution based on the mutual connection between reference values and alternatives. Fuzzy MARCOS was developed in the study (Stanković et al., 2020), and since then it has been exploited in many areas (Ali, 2022; Gölcük et al., 2022; Huskanović et al., 2023; Akram et al., 2023; Tešić et al., 2023; Krishankumar et al., 2023). The algorithm of the F-MARCOS-Z method is shown below.

Step 1. Creation of an initial fuzzy decision matrix based on the ratings of alternative solutions using Z numbers.

Step 2. Conversion of Z numbers into TFNs.

Step 3. Formation of an extended initial fuzzy decision matrix.

$$\widetilde{X} = \begin{matrix} \widetilde{A}(AI) \\ \widetilde{A}_1 \\ \widetilde{A}_2 \\ \dots \\ \widetilde{A}_m \\ \widetilde{A}(ID) \end{matrix} \overset{\begin{matrix} \widetilde{C}_1 & \widetilde{C}_2 & \dots & \widetilde{C}_n \end{matrix}}{\begin{bmatrix} \widetilde{x}_{ai1} & \widetilde{x}_{ai2} & \dots & \widetilde{x}_{ain} \\ \widetilde{x}_{11} & \widetilde{x}_{12} & \dots & \widetilde{x}_{1n} \\ \widetilde{x}_{21} & \widetilde{x}_{22} & \dots & \widetilde{x}_{2n} \\ \dots & \dots & \dots & \dots \\ \widetilde{x}_{m1} & \widetilde{x}_{22} & \dots & \widetilde{x}_{mn} \\ \widetilde{x}_{id1} & \widetilde{x}_{id2} & \dots & \widetilde{x}_{idn} \end{bmatrix}} \tag{18}$$

$\widetilde{A}$ *(AI)* and $\widetilde{A}$ *(ID)* are created by applying Eqs. (19) and (20):

$$\widetilde{A}(AI) = \min_i \widetilde{x}_{ij} \quad if \;\; j \in B \quad and \quad \max_i \widetilde{x}_{ij} \quad if \;\; j \in C \tag{19}$$

$$\widetilde{A}(ID) = \max_i \widetilde{x}_{ij} \quad if \;\; j \in B \quad i \quad \min_i \widetilde{x}_{ij} \quad if \;\; j \in C \tag{20}$$

where B is a set of max type, and C is a set of min type.

Step 4. Defining the normalized fuzzy matrix.

$$\widetilde{n}_{ij} = \left(n_{ij}^l, n_{ij}^m, n_{ij}^u\right) = \left(\frac{x_{id}^l}{x_{ij}^u}, \frac{x_{id}^l}{x_{ij}^m}, \frac{x_{id}^l}{x_{ij}^l}\right) \quad if \;\; j \in C \tag{21}$$

$$\widetilde{n}_{ij} = \left(n_{ij}^l, n_{ij}^m, n_{ij}^u\right) = \left(\frac{x_{ij}^l}{x_{id}^u}, \frac{x_{ij}^m}{x_{id}^u}, \frac{x_{ij}^u}{x_{id}^u}\right) \quad if \;\; j \in B \tag{22}$$

where the elements x_{ij}^l, x_{ij}^m, x_{ij}^u i x_{id}^l, x_{id}^m, x_{id}^u comprise the elements of the matrix $\widetilde{X}$.

Step 5. Determination of the weighted fuzzy matrix $\widetilde{V} = [\widetilde{v}_{ij}]_{m \times n}$.

$$\widetilde{v}_{ij} = \left(v_{ij}^l, v_{ij}^m, v_{ij}^u\right) = \widetilde{n}_{ij} \otimes \widetilde{w}_j = \left(n_{ij}^l \times w_j^l, n_{ij}^m \times w_j^m, n_{ij}^u \times w_j^u\right) \tag{23}$$

Step 6. Computation of fuzzy matrix $\widetilde{S}_i$:

$$\widetilde{S}_i = \sum_{i=1}^{n} \widetilde{v}_{ij} \tag{24}$$

Step 7. Computation of the utility degree of alternatives $\widetilde{K}_i$.

$$\widetilde{K}_i^{-} = \frac{\widetilde{S}_i}{\widetilde{S}_{ai}} = \left(\frac{s_i^l}{s_{ai}^u}, \frac{s_i^m}{s_{ai}^m}, \frac{s_i^u}{s_{ai}^l}\right) \tag{25}$$

$$\widetilde{K}_i^{+} = \frac{\widetilde{S}_i}{\widetilde{S}_{id}} = \left(\frac{s_i^l}{s_{id}^u}, \frac{s_i^m}{s_{id}^m}, \frac{s_i^u}{s_{id}^l}\right) \tag{26}$$

Step 8. Computation of the fuzzy matrix $\widetilde{T}_i$.

$$\widetilde{T}_i = \widetilde{t}_i = \left(t_i^l, t_i^m, t_i^u\right) = \widetilde{K}_i^- \oplus \widetilde{K}_i^+ = \left(k_i^{-l} + k_i^{+l}, k_i^{-m} + k_i^{+m}, k_i^{-u} + k_i^{+u}\right) \tag{27}$$

in order to calculate a new fuzzy number $\widetilde{D}$:

$$\widetilde{D} = \left(d^l, d^m, d^u\right) = \max_i \ \widetilde{t}_{ij} \tag{28}$$

and after that, defuzzification of the number $\widetilde{D}$ is required using the following Eq. (29):

$$df_{crisp} = \frac{l + 4m + u}{6}$$

obtaining a regular number df_{crisp}.

Step 9. Determination of the utility functions of the ideal $f(\widetilde{K}_i^+)$ and the anti-ideal $f(\widetilde{K}_i^-)$ solution.

$$f\left(\widetilde{K}_i^+\right) = \frac{\widetilde{K}_i^-}{df_{crisp}} = \left(\frac{k_i^{-l}}{df_{crisp}}, \frac{k_i^{-m}}{df_{crisp}}, \frac{k_i^{-u}}{df_{crisp}}\right) \tag{30}$$

$$f\left(\widetilde{K}_i^-\right) = \frac{\widetilde{K}_i^+}{df_{crisp}} = \left(\frac{k_i^{+l}}{df_{crisp}}, \frac{k_i^{+m}}{df_{crisp}}, \frac{k_i^{+u}}{df_{crisp}}\right) \tag{31}$$

In the next step should be made defuzzification for $\widetilde{K}_i^-$, $\widetilde{K}_i^+$, $f(\widetilde{K}_i^+)$, $f(\widetilde{K}_i^-)$.

Step 10. Determination of the utility function of alternatives fK_i.

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f\left(K_i^+\right)}{f\left(K_i^+\right)} + \frac{1 - f\left(K_i^-\right)}{f\left(K_i^-\right)}} \tag{32}$$

Step 11. Classification of alternatives according to the descending order of the results obtained.

4. Application of MCDM model for selection of parking places for vehicles with dangerous goods

4.1. Description of the problem

The national regulations of the Republic of Serbia in Article 46, paragraph 13 of the Law on the Transport of Dangerous Goods stipulate that the minister responsible for transport, in agreement with the minister responsible for internal affairs, prescribes places on public roads and the conditions under which vehicles for the transport of dangerous goods can be parked, for the purpose of eliminating defects, exclusion from traffic and control of the transport of dangerous goods. Since this by-law has not yet been prescribed, the following minimum conditions for a parking lot for vehicles with dangerous goods and the conditions under which vehicles can be parked are proposed.

The minimum conditions for a parking lot for vehicles with dangerous goods are as follows:

- ✓ space set aside outside the carriageway,
- ✓ the dimensions of the parking spaces correspond to the type and dimensions of vehicles,
- ✓ parking area marked with adequate traffic signals,
- ✓ parking spaces for vehicles with dangerous goods separated from parking spaces for other vehicles,
- ✓ there are no nearby sewer openings for removing atmospheric sediment, pits or open channels for cables and pipelines,
- ✓ area under video surveillance,
- ✓ location equipped with appropriate firefighting equipment and
- ✓ if possible, a space equipped with a drainage system for collecting dangerous substances in case of leakage.

The conditions under which vehicles with dangerous goods can be parked are as follows:

- ✓ at least 2 m distance from the side in relation to another vehicle or obstacle (danger zone 1),
- ✓ at least 2.5 m distance in front and behind the vehicle in relation to another vehicle or obstacle,
- ✓ enter and leave the parking space by driving forward only,
- ✓ park the vehicle so that it occupies only one parking space provided for that type of vehicle,
- ✓ prohibition of smoking and use of electronic cigarettes or similar devices.
- ✓ banning the use of fire and light sources with open flames.

4.2. Defining parameters – criteria and potential locations

Determining the locations of parking lots for vehicles with dangerous goods was carried out on the road network of IA category - highways on the territory of the Republic of Serbia. The criteria for selection of the location of the parking lot were selected by synthesizing several tools: a review of the literature and a survey of experts in the field of transportation of dangerous goods, based on which the authors, who are also experts in this field, made a definitive opinion on the selection of criteria. The criteria are: C1 - distance from inhabited places, C2 - protection of the environment and distance from watercourses, C3 - properties (industrial, communal, public and other facilities) and C4 - infrastructure available. After determining the essential evaluation criteria, a set of potential locations suitable for the formation of ADR parking places was created. Ninety-two potential parking lots that meet the minimum requirements for parking freight vehicles with dangerous goods have been identified. Existing parking lots and rest areas, toll collection stations, fuel filling stations and potential parking lots were taken into account according to the design and technical documentation of the relevant institutions, which is shown in Fig. 3.

The locations of potential parking lots for vehicles with dangerous

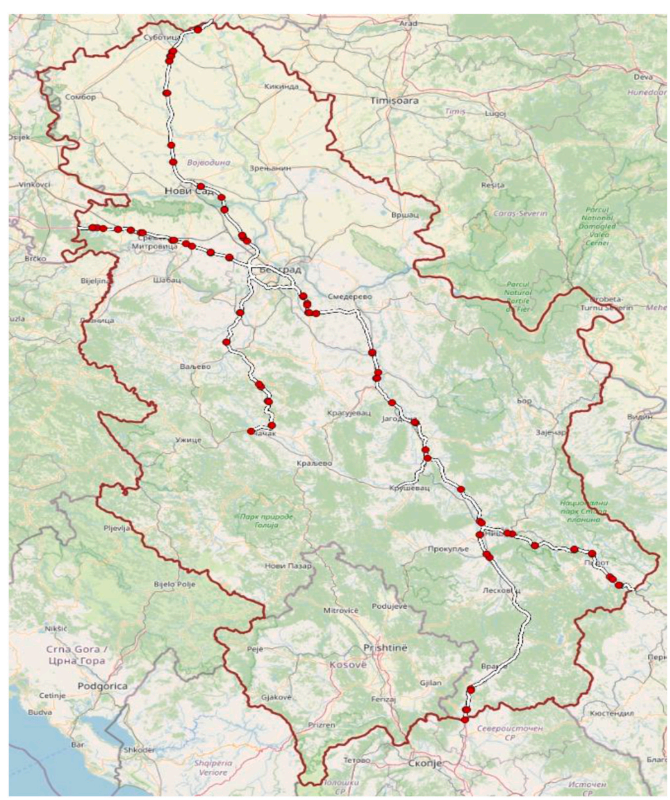

Fig. 3. Highway network in Serbia with 92 potential locations.

Table 3
Sections of highways with their characteristics and the required number of locations.

Road section	Road route	Length	Number of locations by direction	Total
RS1	Batrovci border crossing – Belgrade	110 km	2	4
RS2	Belgrade – Niš	238 km	3	6
RS3	Horgoš border crossing – Belgrade	210 km	3	6
RS4	Niš – Preševo border crossing	155 km	2	4
RS5	Niš - Gradina border crossing	109 km	2	4
RS6	Belgrade – Pakovraće	142 km	2	4
∑		964 km		28

Table 4
Characteristics of experts.

	Profession	Education	Work experience	Institution
E1	University Professor[a]	T&TE	17	FTS NS
E2	University Professor[a]	T&TE	14	FTS NS
E3	University assistant	T&TE	15	ATDEVS Niš
E4	Employee in Practice	T&L	22	Dangerous goods cluster of Serbia
E5	Employee in Practice	T&L	24	GTDGCCV
E6	University Professor	T&TE	21	FTS NS
E7	Employee in Practice	T&L	19	GTDGCCV [b]
E8	University Professor	T&TE	16	FTTE Doboj

FTS NS - Faculty of Technical Sciences Novi Sad, ATDEVS Niš - Academy of Technical-Educational Vocational Studies Niš, GTDGCCV - Group for the transport of dangerous goods at the Chamber of Commerce of Vojvodina, FTTE - Faculty of Transport and Traffic Engineering Doboj.
All experts are certified advisers for safety in the transport of dangerous goods.
[a] Educator at the center for training safety advisors in the transport of dangerous goods.
[b] President.

goods are divided by sections on the IA road network. There are 6 sections in total and potential parking areas for vehicles with dangerous goods are given below by sections. By expert assessment, it has been defined that a minimum of 1 parking lot per 80 km of road is required. Based on that, the number of parking lots per sections, Table 3, is determined, which should be implemented using the new F-PIPRECIA-Z and F-MARCOS-Z model.

4.3. Description of the experts involved in research

As already emphasized, the research includes group decision-making in which eight experts in the field participated, which is shown in Table 4, while Fig. 4 shows their percentage participation in relation to the structure of their characteristics. It is important to emphasize that eight experts participated in the initial decision-making phase in which the significance of the criteria was determined, while seven experts participated in the second phase of evaluating potential locations.

One expert was unable to continue his participation in group decision-making due to personal reasons. Experts are university professors, assistants, or employees in the economic system, in companies with their primary activity related to hazardous substances. It is important to emphasize that the selection of experts has been based on a criterion that they have more than 10 years of work experience. Fig. 4 also provides an overview of institutions where experts are employed. All of them are in the field of transport and traffic engineering or transport and logistics.

When it comes to the percentage of participation of experts in terms of their profession, there is equal participation of university workers and employees in the economic system, while the structure in terms of education is a bit different (63% of transport and traffic engineering and about 38% of transport and logistics). When observing the criterion of work experience, 38% are experts with 16–20 and 20–25 years of experience, and 25% of those with 10–15 years of experience. The largest percentage (38%) is employed at FTS, followed by GTDGCCV with 25%, while other institutions are less represented, with 13% each, FTTE, dangerous goods cluster of Serbia and ATDEVS Niš.

4.4. Computation of criteria weights using the fuzzy PIPRECIA Z method and the fuzzy Dombi aggregator

This section of the paper refers to the computation of criteria weights based on the extended Fuzzy PIPRECIA method with Z numbers and fuzzy Dombi aggregator for weight averaging. First, the experts evaluated the significance of the criteria using linguistic scales, separately for the F-PIPRECIA-Z steps, and for the inverse F-PIPRECIA-Z method (Table 5).

After presenting the assessment data with TFNs and the probability of the appearance of the first component of the Z number, the transformation of the Z number into TFN is started in the following way. If we take the example of F-PIPRECIA-Z for the first expert for C2 then it is: Z number $\widetilde{A}$ =(0.5,0.67,1) and $\widetilde{B}$ = H ((0.55, 0.75, 0.95)). Then α = 0.750 and the converted TFN (0.43,0.58,0.87) is obtained as follows $(\sqrt{0.750}\ \times 0.5, \sqrt{0.750}\ \times 0.67, \sqrt{0.750}\ \times 1)$.

After the complete process of converting Z numbers into TFNs, the following values are obtained for the F-PIPRECIA-Z method, after which its steps are applied.

$$(E_1):(E_2):(E_3):(E_4):$$
$$C_2=(0.43,0.58,0.87), C_2=(0.39,0.48,0.64), C_2=(0.48,0.64,0.97), C_2=(0.43,0.58,0.87)$$
$$C_3=(0.29,0.35,0.43), C_3=(0.64,0.97,0.97), C_3=(1.16,1.26,1.30), C_3=(0.28,0.35,0.47)$$
$$C_4=(1.16,1.26,1.30), C_4=(1.16,1.26,1.30), C_4=(1.13,1.26,1.30), C_4=(0.35,0.43,0.58)$$

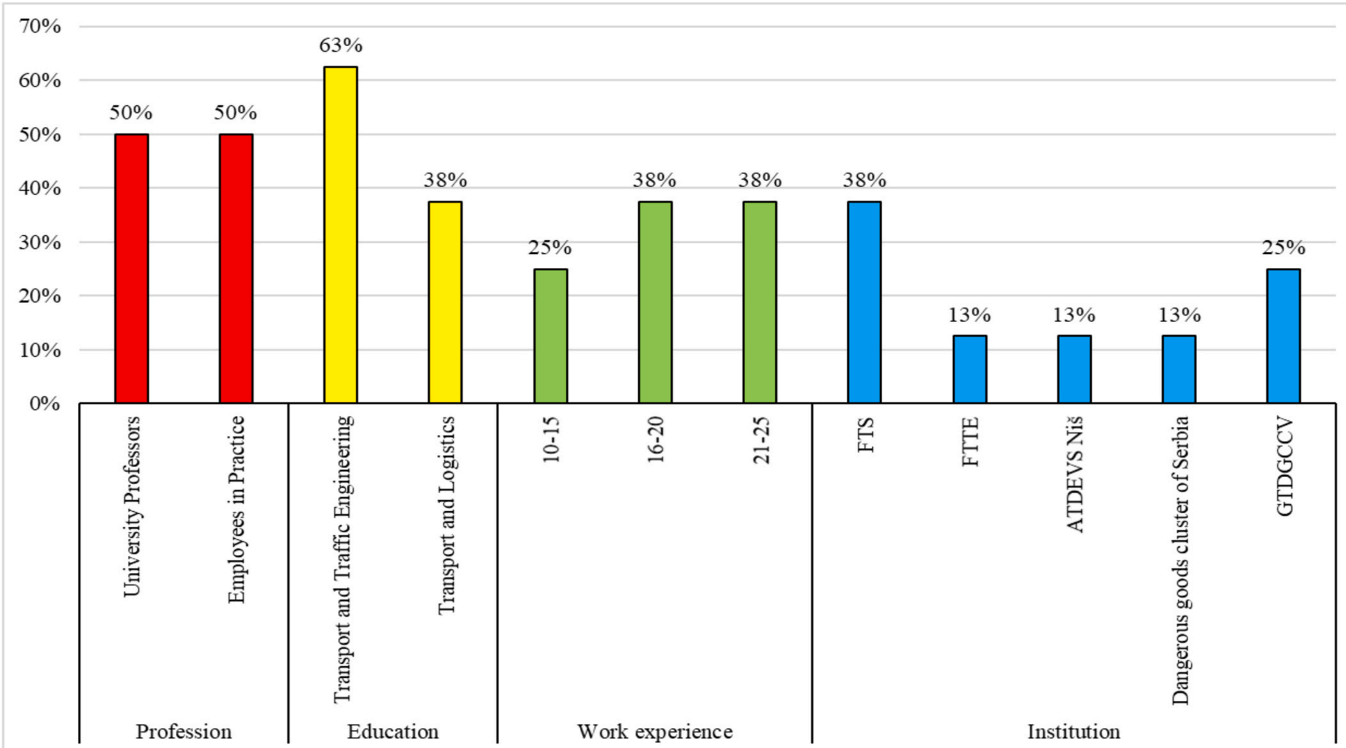

Fig. 4. Structure of the experts.

$(E_5):(E_6):(E_7):(E_8)$:
$C_2=(1.26,1.4,1.45), C_2=(0.58,0.87,0.87), C_2=(1.06,1.11,1.16), C_2=(0.29,0.35,0.43)$
$C_3=(0.28,0.35,0.47), C_3=(0.87,0.87,0.91), C_3=(0.35,0.47,0.71), C_3=(0.29,0.35,0.43)$
$C_4=(1.3,1.52,1.56), C_4=(1.06,1.11,1.16), C_4=(0.87,0.87,0.91), C_4=(1.06,1.11,1.16)$

It is important to emphasize that eight models are calculated, which means one model for each decision-maker. Below is an example of the calculation of weighting coefficients after applying the F-PIPRECIA-Z method for E1.

$$\widetilde{k_1}=(1.000,1.000,1.000)$$

$$\widetilde{k_2}=(2-0.87,2-0.58,2-0.43)=(1.134,1.423,1.567)$$

$$\widetilde{q_1}=(1.000,1.000,1.000)$$

$$\widetilde{q_2}=\left(\frac{1.000}{1.567},\frac{1.000}{1.423},\frac{1.000}{1.134}\right)=(0.638,0.703,0.882)$$

$$\widetilde{q_3}=\left(\frac{0.638}{1.711},\frac{0.703}{1.654},\frac{0.882}{1.567}\right)=(0.373,0.425,0.563)$$

In order to calculate the weighting coefficients, it is necessary to sum up the elements of the previous matrix, so the values (2.45,2.7,3.25) are obtained.

$$\widetilde{w_1}=\left(\frac{1.000}{3.253},\frac{1.000}{2.699},\frac{1.000}{2.455}\right)=(0.307,0.370,0.407)$$

The overall calculation and results for the first expert are shown in Table 6.

The same process is applied to the other seven experts, so the obtained weighting coefficients are shown below for each expert separately.

$(E_1):(E_2):(E_3):(E_4)$:
$\widetilde{w_1}=(0.24,0.34,0.44), \widetilde{w_1}=(0.25,0.3,0.37), \widetilde{w_1}=(0.16,0.2,0.25), \widetilde{w_1}=(0.27,0.35,0.41)$
$\widetilde{w_2}=(0.18,0.27,0.38), \widetilde{w_2}=(0.18,0.21,0.27), \widetilde{w_2}=(0.13,0.17,0.24), \widetilde{w_2}=(0.22,0.28,0.37)$
$\widetilde{w_3}=(0.13,0.18,0.25), \widetilde{w_3}=(0.15,0.19,0.24), \widetilde{w_3}=(0.19,0.25,0.35), \widetilde{w_3}=(0.17,0.21,0.27)$
$\widetilde{w_4}=(0.17,0.21,0.31), \widetilde{w_4}=(0.23,0.3,0.37), \widetilde{w_4}=(0.28,0.38,0.52), \widetilde{w_4}=(0.14,0.16,0.21)$

$(E_5):(E_6):(E_7):(E_8)$:
$\widetilde{w_1}=(0.14,0.16,0.21), \widetilde{w_1}=(0.23,0.28,0.34), \widetilde{w_1}=(0.21,0.28,0.32), \widetilde{w_1}=(0.28,0.40,0.58)$
$\widetilde{w_2}=(0.21,0.27,0.35), \widetilde{w_2}=(0.18,0.24,0.30), \widetilde{w_2}=(0.25,0.30,0.36), \widetilde{w_2}=(0.18,0.24,0.34)$
$\widetilde{w_3}=(0.16,0.20,0.26), \widetilde{w_3}=(0.20,0.23,0.29), \widetilde{w_3}=(0.19,0.23,0.29), \widetilde{w_3}=(0.12,0.16,0.23)$
$\widetilde{w_4}=(0.27,0.37,0.52), \widetilde{w_4}=(0.21,0.25,0.31), \widetilde{w_4}=(0.17,0.20,0.25), \widetilde{w_4}=(0.16,0.20,0.25)$

In order to obtain the average values of the weighting coefficients after the F-PIPRECIA-Z method, the Fuzzy Dombi aggregator is applied as follows:

$$FDO=\left(w_1^l,w_1^m,w_1^u\right)=\begin{cases} w_1^l=\dfrac{\sum_{j=1}^{n}\left(w_j^l\right)}{1+\left\{\sum_{j=1}^{n}w_j^{'}\left(\frac{1-f\left(w_j^l\right)}{f\left(w_j^l\right)}\right)^{\rho}\right\}^{1/\rho}}=\dfrac{1.785}{1+\left(0.125\times\frac{1-0.137}{0.137}\right)+\left(0.125\times\frac{1-0.138}{0.138}\right)+\left(0.125\times\frac{1-0.089}{0.089}\right)+...+\left(0.125\times\frac{1-0.159}{0.159}\right)}=0.211 \\ w_1^m=\dfrac{\sum_{j=1}^{n}\left(w_j^m\right)}{1+\left\{\sum_{j=1}^{n}w_j^{'}\left(\frac{1-f\left(w_j^m\right)}{f\left(w_j^m\right)}\right)^{\rho}\right\}^{1/\rho}}=\dfrac{2.297}{1+\left(0.125\times\frac{1-0.148}{0.148}\right)+\left(0.125\times\frac{1-0.130}{0.130}\right)+\left(0.125\times\frac{1-0.087}{0.087}\right)+...+\left(0.125\times\frac{1-0.174}{0.174}\right)}=0.266 \\ w_1^u=\dfrac{\sum_{j=1}^{n}\left(w_j^u\right)}{1+\left\{\sum_{j=1}^{n}w_j^{'}\left(\frac{1-f\left(w_j^u\right)}{f\left(w_j^u\right)}\right)^{\rho}\right\}^{1/\rho}}=\dfrac{2.919}{1+\left(0.125\times\frac{1-0.151}{0.151}\right)+\left(0.125\times\frac{1-0.127}{0.127}\right)+\left(0.125\times\frac{1-0.084}{0.084}\right)+...+\left(0.125\times\frac{1-0.200}{0.200}\right)}=0.333 \end{cases}$$

where $f((\varphi_1))$ is:

$$f((\varphi_1))=\begin{cases} f\left((\varphi_1)^l\right)=\dfrac{(\varphi_1)^l}{\sum_{i=1}^{8}(\varphi_i)^l}=\dfrac{0.244}{1.785}=0.137; \\ f((\varphi_1)^m)=\dfrac{(\varphi_i)^m}{\sum_{i=1}^{8}(\varphi_1)^m}=\dfrac{0.340}{2.297}=0.148. \\ f((\varphi_1)^u)=\dfrac{(\varphi_1)^u}{\sum_{i=1}^{8}(\varphi_i)^u}=\dfrac{0.439}{2.919}=0.151; \end{cases}$$

For other elements, the same calculation is repeated, and the final criteria values after all steps of F-PIPRECIA-Z and Fuzzy Dombi aggregator are as follows:

$\widetilde{w_1}=(0.211,0.266,0.333)$
$\widetilde{w_2}=(0.184,0.240,0.316)$
$\widetilde{w_3}=(0.159,0.203,0.268)$
$\widetilde{w_4}=(0.191,0.238,0.311)$

The final ranking of the criteria by importance for determining the locations for parking lots for vehicles with dangerous goods is $w_1 > w_2 > w_4 > w_3$, which means that the distance from inhabited places is the most important criterion, and properties are the least important. It is important to note, considering the final values of the criteria, that there is no great difference in their mutual values, which implies that they all have great importance in determining the locations for parking lots for vehicles with dangerous goods.

4.5. Selection of the locations for parking lots for vehicles with dangerous goods using the fuzzy MARCOS Z method and the fuzzy Dombi aggregator

This section of the paper presents the results related to the selection of the 28 most suitable locations for parking lots for vehicles with dangerous goods. As mentioned, a total of 92 locations were considered on six highway sections in two travel directions, which means that it was necessary to create 12 independent MCDM models. Since it is not possible to show all 12 models, the calculation for section RS1 on the road route Batrovci border crossing – Belgrade, 110 km long, direction towards Belgrade, is shown in detail, while only the final results are shown for the other sections. Table 7 provides ratings with Z numbers by seven experts for section RS1 on the road route Batrovci border crossing – Belgrade.

Since the transformation of Z numbers into TFNs and the application of the fuzzy DOMBI operator were previously explained on the example of the calculation of weighting coefficients, below, Table 8 shows the initial matrix for F-MARCOS-Z after applying the procedures explained.

In the next step, it is necessary to determine $\widetilde{A}(AI)$ and $\widetilde{A}(ID)$ in order to form an extended fuzzy matrix.

$$\widetilde{A}(AI)=(0.95,1.55,2.85),(1.38,2.14,2.55),(0.70,1.34,1.78),(1.16,2.01,2.88)$$

$$\widetilde{A}(ID)=(5.51,5.98,7.42),(4.52,5.31,6.64),(5.66,6.65,7.60),(3.10,4.56,5.12)$$

The normalization procedure was performed as follows, and it is shown in Table 9 $\widetilde{n}_{11}=(0.74,0.78,0.98)=\left(\frac{5.51}{7.42},\frac{5.82}{7.42},\frac{7.31}{7.42}\right)$. It is important to note that all criteria are viewed as benefit, because ratings are assigned on the basis of defined scales, which has already been explained.

Applying the other steps of the F-MARCOS-Z method, which involve multiplying the values from the normalized matrix with the weighting coefficients obtained with the F-PIPRECIA-Z method, determining the

Table 5
Assessment of the criteria for evaluating locations for ADR parking lots.

F-PIPRECIA-Z			Inverse F-PIPRECIA-Z		
E1	TFN $\widetilde{A}$	TFN $\widetilde{B}$	E1	TFN $\widetilde{A}$	TFN $\widetilde{B}$
C1	–		C4	–	
C2	(0.5,0.67,1)	H	C3	(1.1,1.15,1.2)	VH
C3	(0.33,0.4,0.5)	H	C2	(1.3,1.45,1.5)	H
C4	(1.2,1.3,1.35)	VH	C1	(0.67,1,1)	VH
E2	TFN $\widetilde{A}$	TFN $\widetilde{B}$	E2	TFN $\widetilde{A}$	TFN $\widetilde{B}$
C1	–		C4	–	
C2	(0.4,0.5,0.67)	VH	C3	(1.2,1.3,1.35)	VH
C3	(0.67,1,1)	VH	C2	(1.1,1.15,1.2)	VH
C4	(1.2,1.3,1.35)	VH	C1	(0.4,0.5,0.67)	S
E3	TFN $\widetilde{A}$	TFN $\widetilde{B}$	E3	TFN $\widetilde{A}$	TFN $\widetilde{B}$
C1	–		C4	–	
C2	(0.5,0.67,1)	VH	C3	(1.1,1.15,1.2)	H
C3	(1.2,1.3,1.35)	VH	C2	(0.4,0.5,0.67)	M
C4	(1.3,1.45,1.5)	H	C1	(0.33,0.4,0.5)	H
E4	TFN $\widetilde{A}$	TFN $\widetilde{B}$	E4	TFN $\widetilde{A}$	TFN $\widetilde{B}$
C1	–		C4	–	
C2	(0.5,0.67,1)	H	C3	(1.1,1.15,1.2)	H
C3	(0.4,0.5,0.67)	M	C2	(1.2,1.3,1.35)	H
C4	(0.4,0.5,0.67)	H	C1	(1.2,1.3,1.35)	H
E5	TFN $\widetilde{A}$	TFN $\widetilde{B}$	E5	TFN $\widetilde{A}$	TFN $\widetilde{B}$
C1	–		C4	–	
C2	(1.3,1.45,1.5)	VH	C3	(0.33,0.4,0.5)	VH
C3	(0.4,0.5,0.67)	M	C2	(1.2,1.3,1.35)	H
C4	(1.5,1.75,1.8)	H	C1	(0.25,0.29,0.33)	M
E6	TFN $\widetilde{A}$	TFN $\widetilde{B}$	E6	TFN $\widetilde{A}$	TFN $\widetilde{B}$
C1	–		C4	–	
C2	(0.67,1,1)	H	C3	(1.1,1.15,1.2)	VH
C3	(1,1,1.05)	H	C2	(0.67,1,1)	VH
C4	(1.1,1.15,1.2)	VH	C1	(1.1,1.15,1.2)	H
E7	TFN $\widetilde{A}$	TFN $\widetilde{B}$	E7	TFN $\widetilde{A}$	TFN $\widetilde{B}$
C1	–		C4	–	
C2	(1.1,1.15,1.2)	VH	C3	(0.67,1,1)	VH
C3	(0.5,0.67,1)	M	C2	(1.1,1.15,1.2)	VH
C4	(1,1,1.05)	H	C1	(1.1,1.15,1.2)	H
E8	TFN $\widetilde{A}$	TFN $\widetilde{B}$	E8	TFN $\widetilde{A}$	TFN $\widetilde{B}$
C1	–		C4	–	
C2	(0.33,0.4,0.5)	H	C3	(1.3,1.45,1.5)	VH
C3	(0.33,0.4,0.5)	H	C2	(1.3,1.45,1.5)	H
C4	(1.1,1.15,1.2)	VH	C1	(0.5,0.67,1)	VH

utility degree and utility functions of the ideal and anti-ideal solution, the final results are obtained for the observed section RS1, for the first direction and are shown in Table 10.

The calculation for the best location has been performed as follows:

Table 6
Results of the F-PIPRECIA-Z method for E1.

	$\widetilde{s_j}$	$\widetilde{k_j}$	$\widetilde{q_j}$	$\widetilde{w_j}$
C1		(1,1,1)	(1,1,1)	(0.31,0.37,0.41)
C2	(0.43,0.58,0.87)	(1.13,1.42,1.57)	(0.64,0.7,0.88)	(0.2,0.26,0.36)
C3	(0.29,0.35,0.43)	(1.57,1.65,1.71)	(0.37,0.43,0.56)	(0.11,0.16,0.23)
C4	(1.16,1.26,1.3)	(0.7,0.74,0.84)	(0.44,0.57,0.81)	(0.14,0.21,0.33)
$\sum$			(2.45,2.7,3.25)	
	$\widetilde{s_j}'$	$\widetilde{k_j}'$	$\widetilde{q_j}'$	$\widetilde{w_j}'$
C1	(1.06,1.11,1.16)	(0.84,0.89,0.94)	(0.9,1.46,1.64)	(0.18,0.31,0.47)
C2	(1.13,1.26,1.3)	(0.7,0.74,0.87)	(0.84,1.3,1.38)	(0.17,0.27,0.4)
C3	(0.64,0.97,0.97)	(1.03,1.03,1.36)	(0.74,0.97,0.97)	(0.15,0.2,0.28)
C4		(1,1,1)	(1,1,1)	(0.2,0.21,0.29)
$\sum$			(3.48,4.73,4.99)	

Normalized fuzzy values have been multiplicated with criteria weights. For example, $\widetilde{v}_{41} = (0.152, 0.214, 0.333) = (0.721 \times 0.211, 0.806 \times 0.266, 1 \times 0.333)$. Then should be calculated fuzzy matrix $\widetilde{S}_i$:

$$\widetilde{S}_4 = \sum_{i=1}^{n} \widetilde{v}_{ij} = (0.436, 0.712, 1.084) = (0.152 + 0.099 + 0.087 + 0.099, 0.214 + 0.159 + 0.126 + 0.212, 0.333 + 0.251 + 0.199 + 0.302)$$

$$\widetilde{K}_4^{\;-} = \frac{\widetilde{S}_4}{\widetilde{S}_{ai}} = (0.895, 2.716, 8.809)\left(\frac{0.436}{0.487}, \frac{0.712}{0.262}, \frac{1.084}{0.123}\right)$$

$$\widetilde{K}_4^{\;+} = \frac{\widetilde{S}_4}{\widetilde{S}_{id}} = (0.355, 0.894, 2.100)\left(\frac{0.436}{1.229}, \frac{0.712}{0.796}, \frac{1.084}{0.516}\right)$$

$$\widetilde{T}_4 = (1.250, 3.610, 10.910) = (0.895 + 0.355, 2.716 + 0.894, 8.809 + 2.100)$$

$$\widetilde{D} = \max_i \ \widetilde{t}_{ij} = (1.250, 3.610, 10.910) \Rightarrow df_{crisp} = 4.433$$

$$f\left(\widetilde{K}_4^{+}\right) = \frac{\widetilde{K}_4^{-}}{df_{crisp}} = \left(\frac{0.895}{4.433}, \frac{2.716}{4.433}, \frac{8.809}{4.433}\right) = (0.202, 0.613, 1.987)$$

$$f\left(\widetilde{K}_4^{-}\right) = \frac{\widetilde{K}_4^{+}}{df_{crisp}} = \left(\frac{0.355}{4.433}, \frac{0.894}{4.433}, \frac{2.100}{4.433}\right) = (0.080, 0.202, 0.474)$$

$$f(K_4) = \frac{K_4^{+} + K_4^{-}}{1 + \frac{1 - f\left(K_4^{+}\right)}{f\left(K_4^{+}\right)} + \frac{1 - f\left(K_4^{-}\right)}{f\left(K_4^{-}\right)}} = \frac{1.105 + 3.428}{1 + \frac{1-0.773}{0.773} + \frac{1-0.227}{0.227}} = 0.943$$

The results on the observed section and direction show the following ranks of potential locations: A4>A6>A3>A7>A8>A5>A2>A9>A1>A10. Considering the road route Batrovci border crossing – Belgrade, the total length of which is 110 km, it is necessary to select the two most suitable locations, namely the existing "Kuzmin" parking lot – direction towards Belgrade, with geographic coordinates: N 45.040378, E 19.365987 and existing "Laćarak" parking lot – direction towards Belgrade, with geographic coordinates: N 45.018522, E 19.521174. The final decision on the number of parking lots will be made by competent authorities in accordance with the criteria they will define. In the same way, the F-PIPRECIA-Z-F-MARCOS-Z model procedure is applied for other road sections and directions, so the set of 28 most suitable locations is given in Fig. 5, and their structure by sections is given in Table 11.

5. Verification tests

In order to test the ranks obtained and select the most suitable locations for parking lots for vehicles with dangerous goods, various verification tests have been created. They include the change of weighting coefficients, comparative analysis, and the calculation of statistical correlation.

5.1. Influence of various values of criteria

This verification test involves the formation of 40 scenarios in which weighting coefficients have been changed. The values of all four criteria were simulated in such a way that they were reduced in the interval 5–95% depending on the specific scenario. The values of the simulated weights in the sensitivity analysis (SA) are presented in Fig. 6.

In scenarios S1–S10, the value of C1 was reduced by 5–95% respectively, which means that from the original value in the initial scenario S0=(0.211,0.266,0.333) was reduced to S10=(0.011,0.013,0.017). Simulated values in S11–S20 reduce the significance of criterion C2: S0=(0.184,0.240,0.316), S20=(0.009,0.012,0.016). In S21–S30, the importance of the third criterion is reduced, while the value of the others increases, so we have S0=

Table 7
Evaluation process by experts for section RS1 on the road route Batrovci border crossing – Belgrade.

	E1								E2							
	C1		C2		C3		C4		C1		C2		C3		C4	
A1	VG	H	L	H	M	S	VP	VH	VG	VH	M	H	P	VS	VP	H
A2	G	H	VL	H	MP	VH	P	M	G	S	M	S	M	M	G	M
A3	VG	H	L	VH	G	VH	MP	M	G	H	MG	VH	MP	M	G	S
A4	VG	VH	VD	VH	EG	M	G	VH	VG	VH	G	S	MG	H	M	M
A5	P	VH	VD	S	MP	M	P	H	MG	H	G	H	M	VS	VG	H
A6	G	H	VD	M	VG	VH	VG	VH	G	VH	MG	S	VG	VH	MP	S
A7	VP	H	D	H	MP	M	VG	H	P	VH	G	H	M	H	P	VH
A8	VG	H	D	M	EP	H	G	M	VG	VS	G	M	P	VH	VG	H
A9	G	H	VD	VH	VG	H	VG	H	MP	VS	EG	VH	EP	S	P	VS
A10	P	VH	M	H	EP	VH	G	H	P	VH	M	H	EP	VH	G	H

	E3								E4							
	C1		C2		C3		C4		C1		C2		C3		C4	
A1	G	H	MP	M	M	H	P	H	VG	H	P	H	G	M	P	M
A2	G	H	MG	M	MP	H	G	H	M	H	P	H	G	M	G	M
A3	G	H	MG	H	MP	H	VG	VH	M	H	MP	H	G	M	G	M
A4	VG	H	VG	H	MG	M	MG	H	M	VH	M	M	G	H	P	M
A5	MG	M	MP	H	MP	M	MG	H	MP	VH	M	M	G	M	G	M
A6	G	H	MP	H	G	H	VG	H	M	H	M	M	G	H	P	M
A7	MG	H	G	H	MP	M	VG	H	P	H	M	H	G	H	P	M
A8	G	M	M	H	MG	H	G	H	MP	M	M	H	MP	M	P	M
A9	MP	H	G	M	MP	H	G	H	MP	H	M	H	G	H	P	M
A10	P	H	MP	M	MP	H	M	M	VP	VH	M	H	P	M	MP	H

	E5								E6							
	C1		C2		C3		C4		C1		C2		C3		C4	
A1	MG	H	EP	H	M	M	M	M	VG	H	VG	H	P	H	VG	H
A2	M	H	P	VH	MP	H	MP	H	VG	H	VG	H	P	H	VG	H
A3	M	H	MP	H	MG	H	M	H	VG	H	VG	H	P	H	VG	H
A4	MG	M	M	M	G	H	MG	H	VG	VH	VG	H	VG	VH	EG	VH
A5	M	H	M	M	P	M	M	VH	VG	H	VG	H	P	H	VG	H
A6	MP	H	MG	H	VG	H	G	H	VG	VH	VG	VH	VG	VH	VG	VH
A7	M	H	G	M	MP	H	G	M	VG	VH	VG	VH	VG	VH	VG	VH
A8	MG	M	G	H	P	M	MG	H	G	H	VG	VH	M	H	VG	VH
A9	M	H	G	H	VG	H	G	M	VG	VH	VG	VH	VG	VH	VG	VH
A10	P	VH	M	H	P	H	VG	M	VP	VH	VP	VH	VP	VH	VG	VH

	E7							
	C1		C2		C3		C4	
A1	VG	M	M	H	P	VH	M	M
A2	VG	VH	MP	H	MP	M	MG	H
A3	VG	VH	MP	H	MP	M	MG	H
A4	VG	VH	MP	H	VG	M	M	H
A5	VG	VH	MP	H	MP	M	MG	H
A6	G	H	MP	H	G	M	M	H
A7	P	H	MP	H	M	H	M	H
A8	G	M	MP	H	P	VH	G	H
A9	MP	M	MP	H	G	M	G	H
A10	VP	H	MP	M	VP	VH	P	M

(0.159,0.203,0.268) and S30=(0.008,0.010,0.013). Finally, in S31–S40, the value of C4 decreases, so we have S0=(0.191,0.238,0.311) and S40=(0.010,0.012,0.016).

By repeating the procedure of applying the F-PIPRECIA-Z-F-MARCOS-Z model, new rankings of locations are obtained, given in Fig. 7.

The SA results show that the model is sensitive to changes in the weighting coefficients, but it is important to note that the first-placed

Table 8
The initial matrix in the F-MARCOS-Z method.

	C1	C2	C3	C4
A1	(5.51,5.82,7.31)	(1.46,2.38,2.55)	(0.7,1.78,1.78)	(1.34,2.01,3.52)
A2	(3.57,4.97,5.25)	(1.38,2.14,3.18)	(2.23,3.19,4.3)	(2.21,3.51,4.16)
A3	(4.05,5.44,5.95)	(2.66,3.6,5.08)	(2.45,3.42,4.64)	(3.1,3.73,4.58)
A4	(5.35,5.98,7.42)	(3.55,4.4,5.26)	(4.15,4.73,5.63)	(2.65,4.56,4.96)
A5	(2.76,4.1,5.16)	(2.2,2.64,3.43)	(1.2,2.1,2.53)	(2.73,4.45,5.12)
A6	(3.67,4.72,5.58)	(3.12,3.4,4.74)	(5.66,6.65,7.6)	(2.58,3.83,4.8)
A7	(1.3,2.38,3.39)	(3.77,4.86,5.6)	(2.54,3,4.07)	(2.12,4.32,4.63)
A8	(3.37,3.75,4.71)	(2.84,3.79,4.34)	(1.27,2.25,2.42)	(2.45,4.14,4.58)
A9	(2.17,2.33,3.51)	(4.52,5.31,6.64)	(2.09,2.18,2.38)	(1.16,2.8,2.88)
A10	(0.95,1.55,2.85)	(2.02,2.46,3.95)	(1.06,1.34,1.9)	(2.5,4.09,4.71)

Table 9
Normalized matrix of the F-MARCOS-Z method.

	C1	C2	C3	C4
AI	(0.13,0.21,0.38)	(0.21,0.32,0.38)	(0.09,0.18,0.23)	(0.23,0.39,0.56)
A1	(0.74,0.78,0.98)	(0.22,0.36,0.38)	(0.09,0.23,0.23)	(0.26,0.39,0.69)
A2	(0.48,0.67,0.71)	(0.21,0.32,0.48)	(0.29,0.42,0.57)	(0.43,0.68,0.81)
A3	(0.55,0.73,0.8)	(0.4,0.54,0.77)	(0.32,0.45,0.61)	(0.61,0.73,0.9)
A4	(0.72,0.81,1)	(0.54,0.66,0.79)	(0.55,0.62,0.74)	(0.52,0.89,0.97)
A5	(0.37,0.55,0.7)	(0.33,0.4,0.52)	(0.16,0.28,0.33)	(0.53,0.87,1)
A6	(0.49,0.64,0.75)	(0.47,0.51,0.71)	(0.74,0.88,1)	(0.5,0.75,0.94)
A7	(0.17,0.32,0.46)	(0.57,0.73,0.84)	(0.33,0.39,0.53)	(0.41,0.84,0.91)
A8	(0.45,0.51,0.63)	(0.43,0.57,0.65)	(0.17,0.3,0.32)	(0.48,0.81,0.89)
A9	(0.29,0.31,0.47)	(0.68,0.8,1)	(0.28,0.29,0.31)	(0.23,0.55,0.56)
A10	(0.13,0.21,0.38)	(0.3,0.37,0.6)	(0.14,0.18,0.25)	(0.49,0.8,0.92)
ID	(0.74,0.81,1)	(0.68,0.8,1)	(0.74,0.88,1)	(0.61,0.89,1)

Table 10
Final results of the F-MARCOS-Z method for road section 1a.

	$f(\widetilde{K}_i^-)$	$f(\widetilde{K}_i^+)$	K-	K+	fK-	fK+	Ki	Rank
A1	(0.05,0.12,0.32)	(0.12,0.37,1.33)	2.180	0.635	0.143	0.492	0.351	**9**
A2	(0.05,0.14,0.35)	(0.12,0.43,1.45)	2.445	0.714	0.161	0.552	0.450	**7**
A3	(0.07,0.17,0.42)	(0.16,0.51,1.74)	2.911	0.850	0.192	0.657	0.655	**3**
A4	(0.08,0.2,0.47)	(0.2,0.61,1.99)	3.428	1.005	0.227	0.773	0.943	**1**
A5	(0.05,0.14,0.35)	(0.12,0.44,1.46)	2.454	0.716	0.162	0.554	0.453	**6**
A6	(0.07,0.18,0.45)	(0.19,0.56,1.9)	3.189	0.932	0.210	0.719	0.801	**2**
A7	(0.05,0.15,0.37)	(0.13,0.47,1.55)	2.616	0.764	0.172	0.590	0.520	**4**
A8	(0.05,0.15,0.34)	(0.14,0.45,1.43)	2.492	0.731	0.165	0.562	0.471	**5**
A9	(0.05,0.13,0.32)	(0.13,0.4,1.34)	2.267	0.663	0.149	0.511	0.383	**8**
A10	(0.04,0.1,0.29)	(0.09,0.32,1.23)	1.917	0.553	0.125	0.432	0.265	**10**

location remains in its position, while the second-placed location is in its position in 92.5% of scenarios, and falls to third place in other cases, specifically in S28–S30 when the value of the third criterion decreases drastically. Also, SA shows that different criteria weights influence locations rank in 72.50%, which means that keep original results in only 11 scenarios i.e. 27.50%. The highest change is with three positions in a few scenarios. Other changes are not too significant, which will be confirmed through correlation coefficients.

5.2. Comparative analysis

The second test involves the selection of the most suitable locations using four MCDM methods based on *Z* numbers: fuzzy SAW (Chou et al., 2008), fuzzy WASPAS (Turskis et al., 2019), fuzzy ARAS (Rostamzadeh et al., 2020) and fuzzy MABAC (Jokić et al., 2021). A comparative analysis (CA) is shown in Fig. 8.

CA results confirm the selection of the two most suitable locations for parking vehicles with dangerous goods, because A4 and A6 do not change their position. The only changes occur with ranks of A2, A5 and A8, which change positions by one place.

5.3. Rank reversal analysis

This part of the paper has performed one type of rank reversal analysis. The worst road section has been eliminated and the total size of the initial matrix has been reduced for one alternative in each scenario. We have formed such nine scenarios, while in the S10 the worst road section A10 has been added to the initial matrix.

Scenario S11 represents replacing the worst road section with the second worst alternative A1, while the last scenario S12 contains three instead of four criteria because the least significant criterion C3 has been eliminated. Results through scenarios have been presented in Fig. 9 (obtained values) and Fig. 10 (ranks).

F-PIPRECIA-Z-F-MARCOS-Z shows characteristics of robustness due to only one change in performed rank reverse analysis from the aspect of road section position i.e. initial rank is same in all sets A4>A6>A3>A7>A8>A5>A2>A9>A1>A10 except S12 in which the second best alternative A6 and third A3 changed their position: A4>A3>A6>A7>A8>A5>A2>A9>A1>A10.

5.4. Correlation tests and deviations

Correlation tests related to the calculation of SCC - Spearman's correlation coefficient (Božanić et al., 2023) and WS - Wojciech Sałabun (Więckowski et al., 2023) coefficients are shown in Fig. 11.

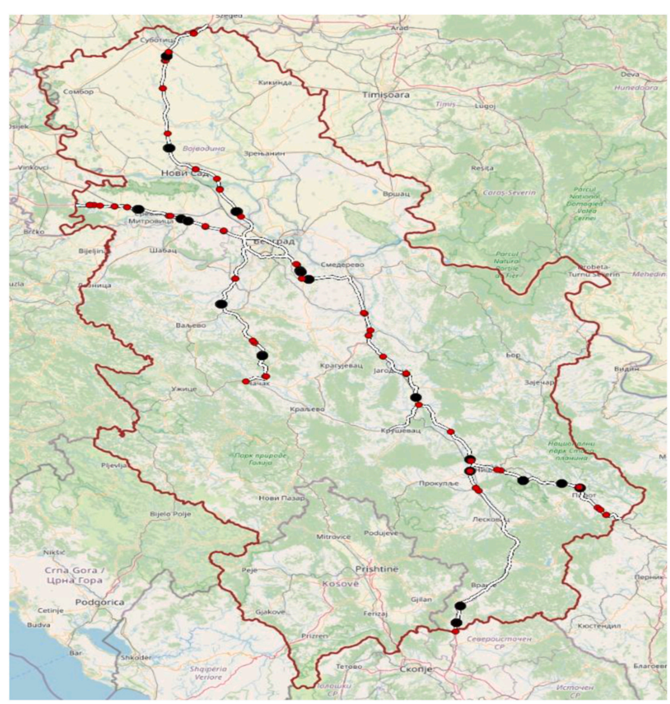

Fig. 5. Locations selected.

Table 11
Structure of selected locations by highway sections and directions.

Section and direction	Locations selected
RS1 on the road route Batrovci border crossing – Belgrade, direction towards Belgrade	The existing parking lot "Kuzmin" and existing parking lot "Laćarak"
RS1 on the road route Batrovci border crossing – Belgrade, direction towards Batrovci border crossing	Expansion and arrangement of the A3 rest area and the existing "Laćarak" parking lot
RS2 on the road route Belgrade - Niš, direction towards Niš	The existing parking lot "Begaljičko Brdo", existing parking lot "Dražanj" and existing parking lot "Krežbinac"
RS2 on the road route Belgrade – Niš, direction towards Belgrade	The parking lot "Trupale", brought to that purpose after the cancellation of the tollbooth, the existing parking lot "Dražanj" and the existing parking lot "Begaljičko Brdo"
RS3 on the road route Horgoš border crossing – Belgrade, direction towards Belgrade	The existing parking lot "Bikovo", the existing parking lot "Sirig" and the expansion and arrangement of the parking lot at the toll station "Stara Pazova"
RS3 on the road route Horgoš border crossing - Belgrade, direction towards Horgoš	The existing parking lot "Sirig", the existing parking lot "Bikovo" and the expansion and arrangement of the parking lot at the toll station "Stara Pazova""
RS4 on the road route Niš - Preševo border crossing, direction towards the Preševo border crossing	The existing parking lot "Čokot", expansion and arrangement of the parking lot at the toll station "Preševo"
RS4 on the road route Niš - Preševo border crossing, direction towards Niš	Expansion and arrangement of the parking lot at the "Preševo" toll collection station and arrangement of the parking lot at the gas station "Valoni Petrol"
RS5 on the road route Niš – Gradina border crossing, direction towards the border crossing Gradina	Arrangement of the parking lot at the "Toplik" rest area and arrangement of the parking lot at the "Sopot" rest area
RS5 on road route Niš – Gradina border crossing, direction towards Niš	Arrangement of the parking lot at the "Sinjac" rest area and arrangement of the parking lot at the "Toplik" rest area
RS6 on the road route Belgrade – Pakovraće, direction towards Pakovraće	Expansion and arrangement of the parking lot at the "Lajkovac" rest area and improvement of the parking lot, heading towards Pakovraće
RS6 on the road route Belgrade – Pakovraće, direction towards Belgrade	arrangement of the parking lot direction towards Belgrade and Expansion and arrangement of the parking lot at the "Lajkovac" direction towards Belgrade

As can be seen, the calculation of the correlation coefficients for the ranks in the previous verification test related to SA has been implemented. Regardless of the fact that in a certain number of scenarios there are differences in the ranks of locations, a general conclusion can be that the ranks in SA are highly correlated, as evidenced by their average values of SCC = 0.946 and WS = 0.981. The lowest correlation is by applying SSC, which is 0.806, and that is in S40, when individual locations change their ranks by more than one position. When it comes to the WS coefficient, the lowest correlation is 0.934 in S30 when the second and third best locations change their positions. In addition to the calculated correlation coefficients, the calculation of the standard deviation is shown in Fig. 12.

Results shown in Fig. 11 are as follows: A1 = 0.791, A2 = 1.346, A3 = 0.418, A4 = 0.000, A5 = 1.165, A6 = 0.264, A7 = 1.063, A8 = 0.925, A9 = 1.167, A10 = 0.435. The deviation in the ranks obtained through the 40 scenarios shows that the most suitable location A4 has no deviations, while the other locations are subject to small deviations. The highest score of deviation is 1.346 for A2.

5.5. Discussion, limitations and implications

Today many MCDM methods in various forms of uncertainty have been available to researchers for decision-making analysis. The proper question is how to select a suitable method or approach to obtain the best results for a unique study. In this paper, we have selected the fuzzy PIPRECIA method for extension due to its advantages like unique linguistic scales for assessment, not required sorting of criteria, application of inverse steps, and calculation of statistics coefficients. In general, these advantages give priorities in comparison to other MCDM methods for determining criteria weights like BWM (Rezaei, 2015; Bonab et al., 2023), AHP (Saaty, 1982; Chen et al., 2023), and LBWA (Žižović and Pamučar, 2019; Ogundoyin and Kamil, 2023). Also, for selection of the most suitable locations for parking vehicles with dangerous goods has been chosen MARCOS method due to many good performances like stability of the model, robustness, calculation of utility function from ideal and antiideal solutions, the possibility to consider a large set of criteria and alternatives while maintaining the stability of the method. In general, these advantages give priorities in comparison to other MCDM methods for ranking variants like TOPSIS (Petrović et al., 2023), COMET (Shekhovtsov et al., 2022), SPOTIS (Bączkiewicz, 2022), EDAS (Keshavarz Ghorabaee et al., 2015; Radovanović et al., 2023).

Limitations of this model can be manifested through the fact that

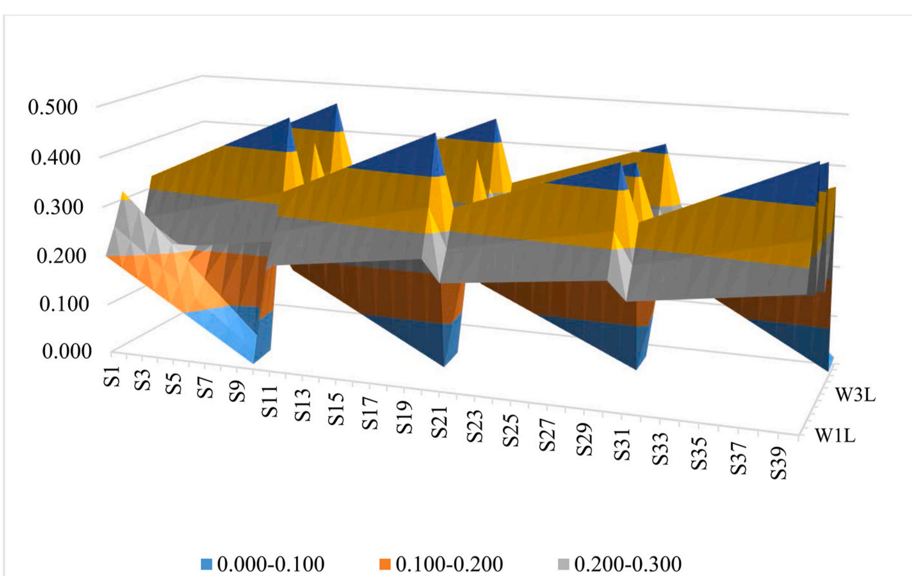

Fig. 6. Values of criteria in 40 scenarios.

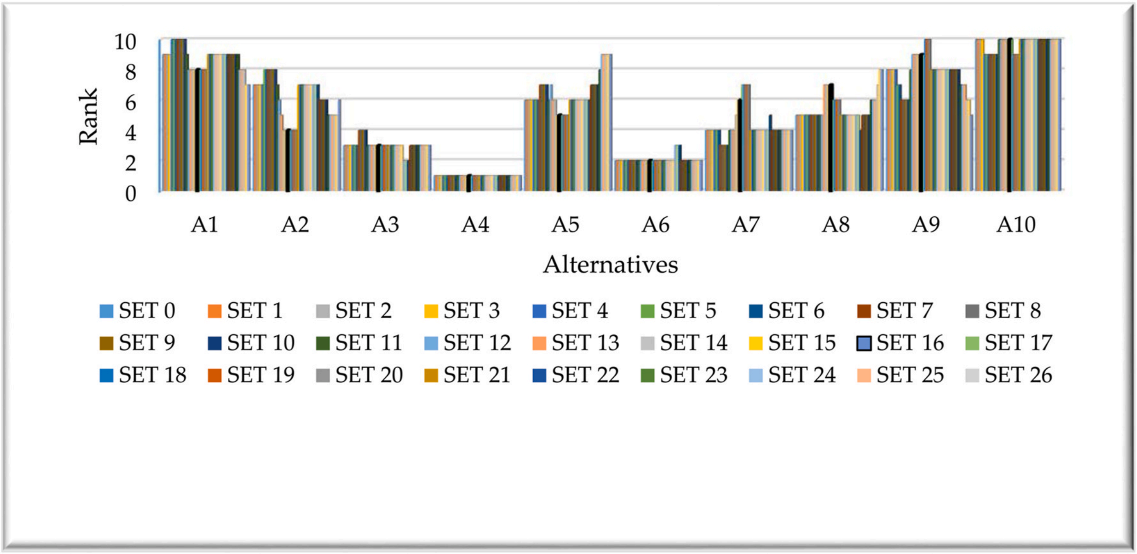

Fig. 7. Ranks in SA

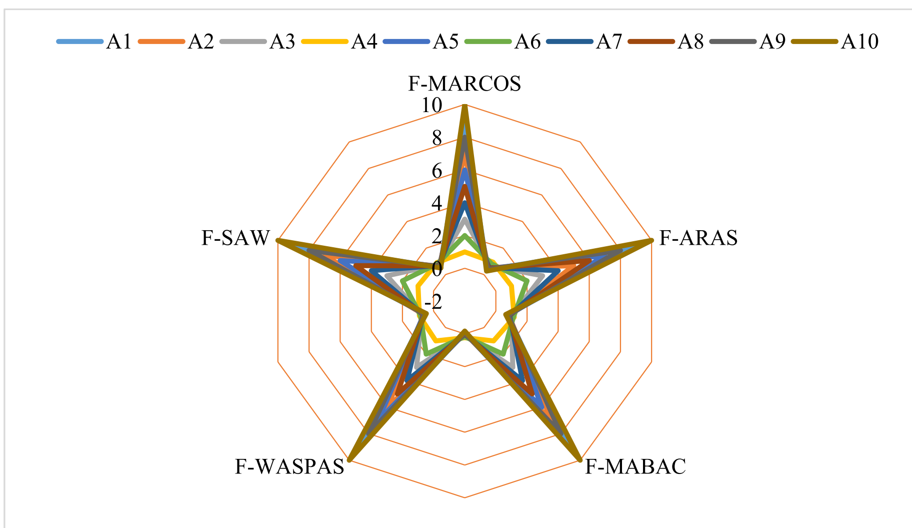

Fig. 8. Results of CA

research is not finished, due should be created separated model for determining a final number of locations. For this purpose can be used GIS with the implementation of criteria weights determined in this part of the research. Limitations can be manifested through the small number of observed criteria involved in the model and the fact that the base of the ministry related to potentially suitable locations for parking vehicles with dangerous goods is in the initial stage.

Managerial implications are directly related to political implications because decision about a final number of locations should be made by the responsible ministry. They can take into account the proposed model in total or partly depending on their conditions and circumstances. Currently, the field of parking vehicles with dangerous goods is not regulated at the global level, so it is left to the state authorities to regulate this area independently. As the awareness of the risks in the transport of dangerous goods and environmental protection grows, it is expected that the state authorities will be more active in the field of parking vehicles with dangerous goods. It is necessary to include a large number of experts in the activity of editing this area to exclude subjectivity and pass appropriate legal acts.

6. Conclusion

This study presents extensive research related to defining the most suitable potential locations for parking lots for freight vehicles transporting hazardous materials. For this purpose, an original MCDM model called F-PIPRECIA-Z-F-MARCOS-Z has been developed, and it involves the integration of various methods with Z numbers. It is important to emphasize that for the first time in the literature, the extension of the fuzzy PIPRECIA method with Z numbers has been presented in order to determine the weighting coefficients of four criteria relevant to the evaluation of potential locations with greater precision. Certainly, the development of such a model, which can be implemented in various fields and which enriches the literature, represents a clear contribution from the scientific aspect. From the social and professional aspect, the advantage of the model can be reflected through its adaptation to specific conditions that prevail in real time, whereby, depending on their own social, technological, ecological and economic needs and requirements, competent personnel can model the results. By taking into account the aforementioned, the personnel determine the significance of the criteria on the basis of which evaluation is performed or input

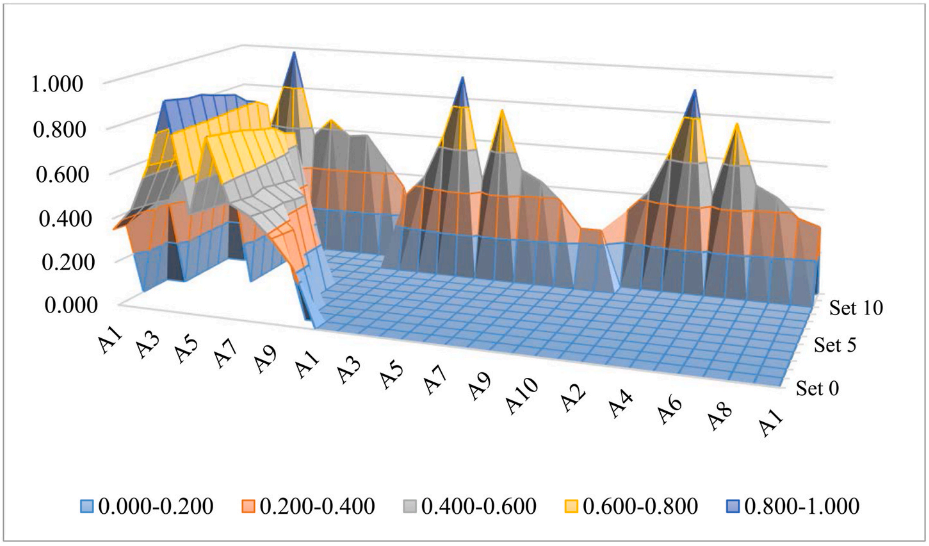

Fig. 9. Values of alternatives in reverse rank analysis.

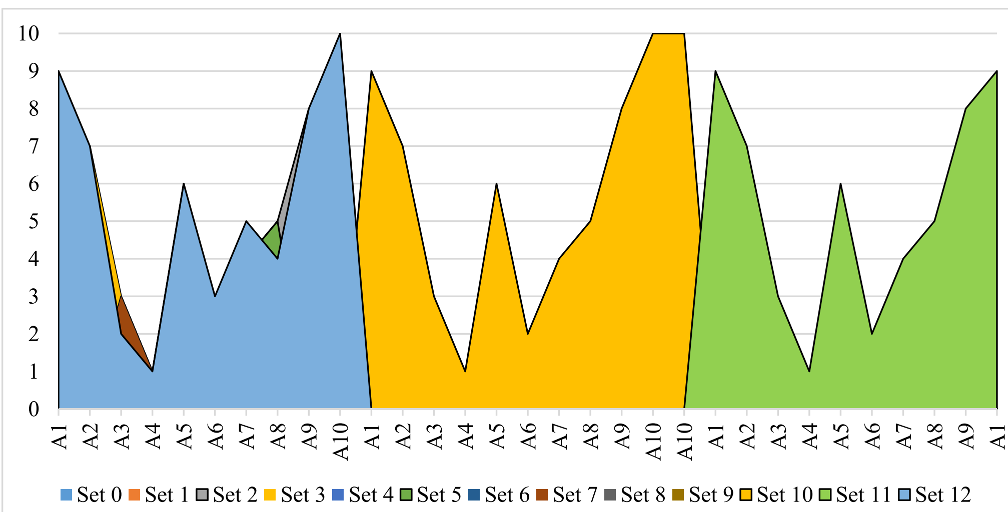

Fig. 10. Ranks in rank reversal analysis.

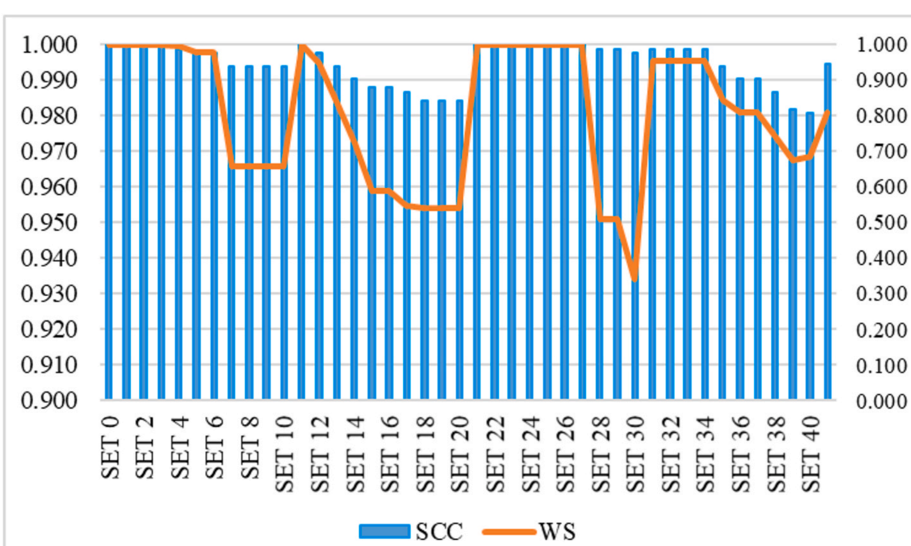

Fig. 11. SCC and WS in SA

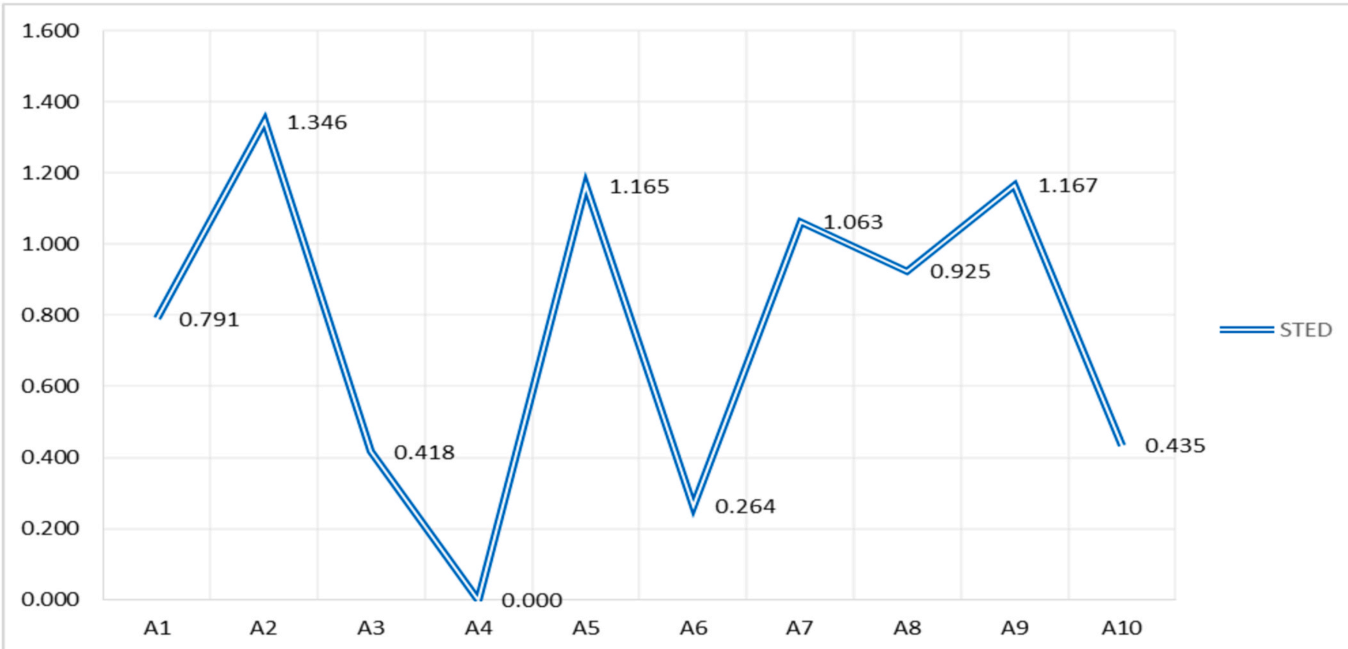

Fig. 12. Stdev in SA

parameters are changed. Managerial implication refers to the fact that the model developed as part of this research can serve decision-makers at competent institutions to define the number and exact layout of parking lots for vehicles with dangerous goods that have the best characteristics, because the final decision on the number of parking lots is made by the competent authorities in accordance with the criteria they will define.

In the model defined, a total of 92 potential locations on the total highway length of 964 km were taken into consideration. The overall structure of the highway refers to six sections, considering both directions, thus it is evident that 12 models had to be applied in order to select the desired set of the most suitable locations, which was 28 according to the criteria set by the experts. Taking into account that the length of the sections is from 109 to 238 km, two or three locations were selected per section and per direction, depending on the length of the sections. In the paper, the model developed is elaborated in detail through the example of one highway section in one direction, while the results are presented for all 12 models. Further research involves the formation of different scenarios that will consist of several locations out of the 28 selected, taking into account the criterion of their least mutual distance. It is necessary to form scenarios for both directions of all highway sections, and make a decision recommending to competent institutions the exact number and locations for parking lots for vehicles with dangerous goods. In addition, further research should include monitoring of future parking lots and responding in accordance with future needs.

CRediT authorship contribution statement

Dragan Smiljanić: Writing – original draft, Formal analysis, Data curation, Conceptualization. **Siniša Sremac:** Writing – original draft, Supervision, Methodology, Conceptualization. **Ilija Tanackov:** Supervision, Project administration, Formal analysis. **Željko Stević:** Writing – review and editing, Validation, Methodology. **Peter Márton:** Writing – review and editing, Visualization, Supervision. **Gordan Stojić:** Writing – review and editing, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Abbreviations

ADR Agreement concerning the International Carriage of Dangerous Goods by Road
FACTS Failure and Accidents Technical information System
USA United States of America
MCDM Multi-Criteria Decision Making
PIPRECIA PIvot Pairwise RElative Criteria Importance Assessment
F-PIPRECIA Fuzzy PIvot Pairwise RElative Criteria Importance Assessment
MARCOS Measurement of Alternatives and Ranking according to the Compromise Solution
F-MARCOS Fuzzy Measurement of Alternatives and Ranking according to the Compromise Solution
GIS Geographic Information System
AHP Analytical Hierarchy Procedure
TDG Transport Of Dangerous Goods
DEMATEL Decision Making Trial And Evaluation Laboratory
3 PL Third-Party Logistics Providers
TOPSIS Technique for Order of Preference by Similarity to Ideal Solution
LNN WASPAS Linguistic Neutrosophic Numbers Weighted Aggregated Sum Product Assessment
QFD Quality Function Deployment
FMEA Failure Mode and Effects Analysis
SWARA Stepwise Weight Assessment Ratio Analysis
IMF SWARA IMproved Fuzzy Stepwise Weight Assessment Ratio Analysis
FTA Fault tree analysis

ITARA Indifference Threshold-based Attribute Ratio Analysis
EDAS Evaluation Based On Distance From Average Solution
TFN Triangular Fuzzy Number
FTS NS Faculty of Technical Sciences Novi Sad
ATDEVS Niš Academy of Technical-Educational Vocational Studies Niš
GTDGCCV Group for the transport of dangerous goods at the Chamber of Commerce of Vojvodina
FTTE Faculty of Transport and Traffic Engineering Doboj
RS Road Section
SA Sensitivity Analysis
CA Comparative Analysis
SAW Simple Additive Weighting
ARAS Additive Ratio Assessment
MABAC Multi-Attributive Border Approximation Area Comparison
SCC Spearman's correlation coefficient
WS Wojciech Sałabun coefficient
BWM Best Worst Method
LBWA Level Based Weight Assessment
COMET Characteristic Objects Method
SPOTIS Stable Preference Ordering Towards Ideal Solution

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