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An Intelligent Fuzzy MCDM Model Based on D and Z Numbers for Paver Selection: IMF D-SWARA—Fuzzy ARAS-Z Model

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Abstract: One of the most important challenges when building road infrastructure is the selection of appropriate mechanization, on which the efficiency of construction and the life of exploitation depends largely. As construction machinery, pavers occupy a significant place in civil engineering projects, so their selection, depending on a road category, is a very important activity. The objective of this paper is to develop an intelligent Fuzzy MCDM (Multi-Criteria Decision-Making) model, which consists of the integration of D and Z numbers for the selection of construction machinery. The IMF D-SWARA (Improved Fuzzy D Step-Wise Weight Assessment Ratio Analysis) method was used to determine weighting coefficients. A novel Fuzzy ARAS-Z (Additive Ratio Assessment) method has been developed to determine an adequate paver for a lower category of roads (asphalt width up to 5 m), which represents an important contribution and novelty of the paper. A total of 10 alternatives were evaluated based on 16 criteria which were classified into 4 main groups. The results have shown that the alternative A8—SUPER 1300-3 represents a paver with the best characteristics for the considered set of parameters. After that, verification tests were calculated, and they include a comparative analysis with four other MCDM methods based on Z numbers, a change in the normalization procedure, and the impact of changing the size of an initial fuzzy matrix. The tests showed the stability of the developed model with negligible deviations.

Keywords: paver; MCDM; Z numbers; fuzzy ARAS-Z; road infrastructure; construction

MSC: 90B20; 90B20; 90b50

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1. Introduction

Every year, the world's population is increasing, and such a trend should continue in the future [1]. The increased population creates a greater need for infrastructure construction, such as residential buildings and transport infrastructure for connecting cities and transporting people and goods. An additional reason for new infrastructure is the deterioration of already existing infrastructure due to the effects of loads and external impacts. It is possible for the existing infrastructure to be reconstructed at appropriate time intervals. Whether it is the construction of new or the reconstruction of existing infrastructure, construction machinery is required. The type of construction machinery depends on the type of building it is being built. Thus, it is possible to use excavators, trucks, graders, rollers and pavers [2,3].

In this paper, the authors limited themselves to mechanization for the construction of transport infrastructure. Transport infrastructure requires large amounts of money for construction on the one hand, but, on the other hand, it can have a significant impact on the development of the country's economy [4–6]. When building transport infrastructure, the main principle we are guided by is to obtain the best possible quality for as little money as possible. It is important to emphasize that the ratio between construction costs and future maintenance costs is also significant. The more material resources are invested in construction, the less the amount of funds available for maintenance and vice versa. The cost of infrastructure construction is influenced by many factors such as the type of road, the price of component materials, the complexity of the terrain on which the road is being built, the number of constructions (bridges and tunnels) that are being built on the route, the weather conditions in which the road is being built and many other factors. For the construction of transport infrastructure, construction machinery is used. Depending on its properties, it can affect the speed of the execution of works and, therefore, the price of the works. From the available division of mechanization for the construction of transport infrastructure, in this research, the authors selected pavers since there is an objective need for them. Pavers are machines that are used to install asphalt mixes in the layers of pavement structure. In recent times, pavers have also been used to make layers of crushed stone. Road construction usually has several layers, and their upper layers are made of asphalt. Asphalt mixtures can be installed using excavators and graders, but the most dominant and high-quality method is by using a paver. The main parts of the paver are paving material tank, conveyor belt, augers, tamper and screed [7]. Pavers differ from each other in working widths, tank capacities, conveyor belt speeds, the speed of the paver itself, engine power, width, length, height, weight, etc. Roads and road infrastructure are classified in different ways depending on criteria. In Serbia, where data have been collected for research, there are many divisions, and some of them are a division based on the administrative criterion, functional classification and classification based on terrain type.

In general, considering all these categories, it is evident that the categories differ according to the types of cross sections, the number of traffic lanes, the width of individual lanes as well as the total width of the roadway. It is these data regarding road categories that are significant when deciding on the type of paver. It reflects the importance of this scientific paper in which a novel original IMF D-SWARA-ARAS-Z model for multi-criteria evaluation of pavers has been developed and presented for the first time in the literature. In this way, emphasis has been given to the methodological aspect of this paper and the further possibility of applying the developed model to solve any problem in different areas of decision-making. Therefore, the aim of the paper implies the selection of an adequate paver as construction machinery for the construction of roads with a roadway width not exceeding five meters. Another important contribution and novelty that is significant to emphasize is the integration of D and Z numbers in the Fuzzy MCDM model, which, according to the literature search, has also been presented in this paper for the first time.

The further structure of the paper includes six other sections in which the research is explained in detail from the aspect of reviewing similar studies in the field, a detailed presentation of the developed Fuzzy MCDM model, a description of a case study with explanations of the parameters of the MCDM model, its application in the selection of a paver with certain overviews of calculation details, validity tests and concluding considerations.

2. Literature Review

The cost of infrastructure construction is influenced by many factors, such as the type of a road, the price of component materials, the complexity of the terrain on which the road is being built, the number of constructions (bridges and tunnels) that are being built on the route, the weather conditions in which the road is being built and many other factors. For the construction of transport infrastructure, we use construction machinery, which, depending on its properties, can affect the speed of the execution of works and, therefore, the price of the works.

Based on all of this, it can be said that it is very important to have appropriate and optimal selection of road construction mechanization. Optimal mechanization selection can be made using MCDM models. MCDM methods [8] were applied in civil engineering for the first time in the 1990s and in the research by Duckstein et al. [9]. Temiz and Calis [10] used MCDM methods to select an appropriate excavation machine for a construction site. In the study, the authors analyzed qualitative and quantitative criteria including technical specifications, purchasing cost, fuel consumption, service conditions, secondary and replacement parts markets and comfort of the operator. In their study, the authors used the Analytical Hierarchy Process (AHP) and the Preference Ranking Organization Method for Enrichment of Evaluation (PROMETHEE). Ivanović et al. [11] applied a MCDM method to select a truck mixer concrete pump. The authors used the MEREC (method based on the removal effects of criteria) and the DNMARCOS (double normalized measurement alternatives and ranking according to the compromise solution) method to select construction equipment among 16 alternatives. Ghorabaee et al. [12] presented the extension of the classical SWARA (Step-Wise Weight Assessment Ratio Analysis) and CRITIC (CRiteria Importance Through Intercriteria Correlation) methods in order to evaluate construction equipment considering sustainability. Further, integrating the extended SWARA and CRITIC methods with the fuzzy EDAS methods, was proposed as a novel approach. Phogat and Singh [13] applied five multi-criteria decision-making methods to select machines for hilly road construction. The authors examined the following five methods: AHP, SAW, Distance Based Method (DBM), PROMETHEE and Elimination Et Choice Translating Reality (ELECTRE).

Additionally, multi-criteria analysis can be useful in processes of route planning, design, selection of the most proper maintenance and reconstruction solution [14]. According to the literature review, the authors concluded that the AHP method was mostly applied when designing and constructing roads and transport infrastructure. Some other authors came to similar conclusions [15]. Analytical Hierarchy Process (AHP), Simple Additive Weighting (SAW), Fuzzy Overlay, Promethee and TOPSIS, which are methods of Multi-Criteria Decision Making (MCDM), were also used to determine a forest road route in the Black Sea region of Turkey [16]. The selection of an optimal highway route to connect Rijeka, Koper and Trieste was completed by using the PROMETHEE II method. Five road route alternatives were ranked using five groups of criteria (economic, transport, constructional-technical, urban planning and eco-sociological), including 26 sub-criteria [17]. Sekulić et al. [18] selected an optimal road route using a spatial multi-criteria method. The authors conducted a case study in the Tlokweng region in Botswana. The study included 13 criteria that were used to evaluate alternatives. The criteria were arranged into three groups: economic, environmental and social criteria.

A multi-criteria decision making, along with graphic displaying, was used to find a solution for a parking layout of freight transport in Slovakia [19]. Marzouk and Abdelakder [20] used multi-criteria optimization and decision-making in order to decrease environmental pollution in construction projects. Marcelino et al. [21] developed a multi-criteria decision-making model for identifying road maintenance and rehabilitation at the network level in Portugal. The authors used the MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) method as an alternative to the AHP method. The model was based on technical, economic and social criteria.

3. Methods

In this section, the algorithm of the developed MCDM model based on Z numbers is presented in detail. As noted, this research is part of a larger project that involved the selection of construction machinery for the middle, lower category of roads, as well as for highways. The decision-making model for the selection of a paver for the middle category of roads was developed in the paper [22] in which the weights of the criteria were defined with the IMF D-SWARA method. Those weighting coefficients have been used in this paper and integrated with a novel MCDM model for ranking pavers based on Z numbers.

3.1. Z Numbers

Z-numbers represent an ordered pair of fuzzy numbers, $Z = (\widetilde{A}, \widetilde{B})$. The first component is the fuzzy number $\widetilde{A}$ and is the fuzzy limit of a variable X, while the second component is the fuzzy number $\widetilde{B}$ and is the reliability of the first component ($\widetilde{A}$). In Figure 1, the form of the Z-number with triangular fuzzy numbers is presented [23].

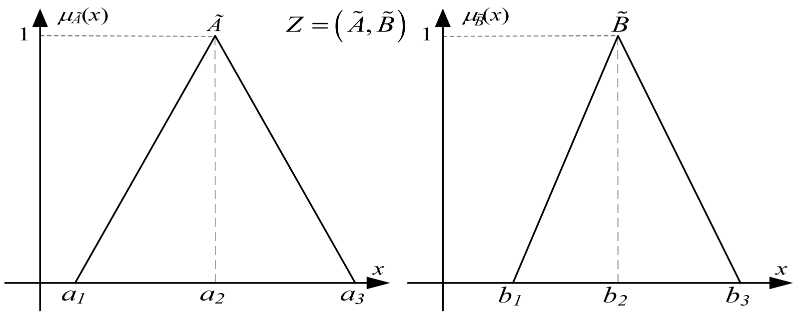

Figure 1. Z-number [24].

A general form of triangular Z-numbers can be presented as follows:

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

where the values $w_{\widetilde{A}}$ and $w_{\widetilde{B}}$ represent the weight factors of fuzzy number $\widetilde{A}$ referring to $\widetilde{B}$, which is, for the initial Z-number, defined by most authors as $w_{\widetilde{A}} = w_{\widetilde{B}} = 1, w_{\widetilde{A}}, w_{\widetilde{B}} \in [0,1]$ ($w_{\widetilde{A}}$ is the height of generalized fuzzy number and $0 \leq w_{\widetilde{A}} \leq 1$) [25]. Based on the evidence, the Z-number is converted into a classic fuzzy number through the following steps:

Converting the second part ($\widetilde{B}$) into a crisp number by applying the centered method:

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

Adding the weight of the second part ($\widetilde{B}$) to the first part ($\widetilde{A}$). The weighted Z-number is given as follows:

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

and it is presented as

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

Converting the weighted Z-number into a regular fuzzy number. The regular fuzzy can be given as

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

3.2. IMF D-SWARA Algorithm

IMF SWARA is more recent, and it has already been applied in various studies [26–28]. The SWARA method [29] in combination with D numbers [30] as already defined was applied to determine the weights of the criteria for the whole project of evaluation and selection of pavers for all road categories. The detailed IMF D-SWARA algorithm is shown in the paper [22], and the weights are shown further in the paper.

3.3. Fuzzy Bonferroni Mean (BM) Operator

Since it was a group decision making [31] in which four experts participated, it is necessary to determine the expert ratings after the transformation of Z numbers to obtain an initial fuzzy decision matrix. For this purpose, a fuzzy Bonferroni aggregator was used [32].

$$\tilde{a}_{ij} = (a^l_{ij}, a^m_{ij}, a^u_{ij}) = \begin{cases} a^l_{ij} = \left(\frac{1}{e(e-1)} \sum\limits_{\substack{i,j=1 \\ i \neq j}}^{e} a_i^{lp} \otimes a_j^{lq} \right)^{\frac{1}{p+q}} \\ a^m_{ij} = \left(\frac{1}{e(e-1)} \sum\limits_{\substack{i,j=1 \\ i \neq j}}^{e} a_i^{mp} \otimes a_j^{mq} \right)^{\frac{1}{p+q}} \\ a^u_{ij} = \left(\frac{1}{e(e-1)} \sum\limits_{\substack{i,j=1 \\ i \neq j}}^{e} a_i^{up} \otimes a_j^{uq} \right)^{\frac{1}{p+q}} \end{cases} \tag{6}$$

where e is the number of experts participating in the research, and p, $q \geq 0$ are a set of non-negative numbers.

3.4. Fuzzy ARAS Method Based on Z Numbers

The ARAS method has undergone many modifications since its original form [33] until today [34,35] and has been applied in various fields.

In this section, the steps of the novel approach, which involves the integration of the Fuzzy ARAS method with Z numbers, are presented.

1. Define the required number of criteria and alternatives, followed by the formation of an MCDM model based on the performance of m alternatives evaluated on the basis of n criteria.

$$\tilde{\Psi} = \begin{bmatrix} \widetilde{\psi_{i1}} & \widetilde{\cdots} & \widetilde{\psi_{ij}} & \widetilde{\cdots} & \widetilde{\psi_{in}} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \widetilde{\psi_{m1}} & \widetilde{\cdots} & \widetilde{\psi_{mj}} & \widetilde{\cdots} & \widetilde{\psi_{mn}} \\ \widetilde{\psi_{o1}} & \widetilde{\cdots} & \widetilde{\psi_{oj}} & \widetilde{\cdots} & \widetilde{\psi_{on}} \end{bmatrix} \tag{7}$$

Unlike most other methods, ARAS is extended with an additional alternative that implies the optimal value of the alternative according to a certain criterion depending on its orientation as defined in Equations (8) and (9).

$$\widetilde{\psi_{oj}} = \max \widetilde{\psi_{ij}} \; if\; j\; prefer\; \text{max}imum \tag{8}$$

$$\widetilde{\psi_{oj}} = \min \widetilde{\psi_{ij}} \; if\; j\; prefer\; \text{min}imum \tag{9}$$

2. Performing the normalization procedure depending on a type of criteria.

The criteria that prefer maximum values are normalized as follows:

$$\widetilde{\varsigma_{ij}} = \frac{\widetilde{\psi_{ij}}}{\sum\limits_{i=1}^{o} \widetilde{\psi_{ij}}} \tag{10}$$

The criteria that prefer minimum values are normalized as follows:

$$\widetilde{\varsigma_{ij}} = \frac{\frac{1}{\widetilde{\psi_{ij}}}}{\sum\limits_{i=1}^{o} \frac{1}{\widetilde{\psi_{ij}}}} \tag{11}$$

3. Multiplication of the normalized fuzzy Z matrix with previously calculated criterion weights *wj*.

$$\widetilde{\gamma_{ij}} = \widetilde{\varsigma_{ij}} \otimes \widetilde{w_j} \tag{12}$$

4. Determining the optimality function:

$$\widetilde{\mathrm{O}_i} = \sum_{j=1}^{n} \widetilde{\gamma_{ij}} \tag{13}$$

where O_i is the value of the function for i alternatives.

5. The utility degree of alternatives is calculated by comparing the analyzed alternatives with the optimal one, which is denoted O_o.

$$\widetilde{\mathrm{A}_i} = \frac{\widetilde{\mathrm{O}_i}}{\widetilde{\mathrm{O}_o}} \tag{14}$$

The calculated values of A_i should be arranged in descending order, thus obtaining the ranks of the alternatives.

In addition to the previously defined steps of the Fuzzy ARAS-Z method, a scale for evaluating alternatives, which is shown in Table 1, is defined.

Table 1. Scale for evaluating using a Fuzzy ARAS-Z method.

Linguistic Variable	TFN A	Linguistic Variable	TFN B
Extremely poor—EP	(1, 1, 1)	Very small (VS)	(0, 0, 0.2)
Very poor—VP	(1, 1, 3)	Small (S)	(0.1, 0.25, 0.4)
Poor—P	(1, 3, 3)	Medium (M)	(0.3, 0.5, 0.7)
Medium poor—MP	(3, 3, 5)	High (H)	(0.55, 0.75, 0.95)
Medium—M	(3, 5, 5)	Very high (VH)	(0.8, 1, 1)
Medium good—MG	(5, 5, 7)		
Good—G	(5, 7, 7)		
Very good—VG	(7, 7, 9)		
Extremely good—EG	(7, 9, 9)		

4. Formulation of the MCDM Model

As stated in the introduction, there are several criteria based on which the road infrastructure in Serbia is classified. The administrative criterion divides roads into state and municipal roads depending on the road authority. According to the function they perform in a road network, the functional criterion divides roads into long-distance, connecting, feeder and access roads. According to the type of terrain on which roads are built, there are the following categories: mountainous, hilly, steep and plain. All the mentioned categories observe the roads in terms of one criterion. One criterion could be defined as common when observing most of these categorizations: the roadway width. Considering larger categories, it can be seen that there is a larger width of the roadway, and conversely, a smaller road category means a smaller width of the roadway. Due to these variations in the categories, for the purposes of this paper, and also in a previously published paper related to a similar topic but a different road category and a different methodology [22], the following width categories were adopted:

Category 1—asphalting width is up to 5 m.
Category 2—asphalting width is from 5 m to 10 m.
Category 3—asphalting width is over 10 m.

This paper presents the evaluation of paver performance for category 1 with the smallest width.

4.1. Description of the Problem

This section of the paper presents data on all alternatives that were considered during the selection of the most suitable paver. Data on ten alternatives of different types of manufacturers are presented. After the alternatives presented, an overview of the criteria based on which the evaluation was carried out was given. The criteria were established after reviewing the literature related to construction machinery as well as the catalogs of various paver manufacturers. After that, consultations with experts dealing with the production and installation of asphalt mixes were held. The experts in the field of asphalt mixtures, based on their experience and daily dealing with asphalt mixtures, provided guidelines used to adopt the final criteria. In the end, the authors of this paper decided to accept 16 criteria, which were then divided into four groups: speed criteria, which refer to the speed of the paver and the speed of asphalt mixture installation; technical and technological criteria, which refer to the capacities of the paver; dimension criteria, which refer to the dimensions of machines; and the adopted criteria include concepts related to economy, exploitation and environmental protection (EEE).

4.2. Definition of Alternatives

Data on pavers of three manufacturers were collected: Vögele, Caterpillar and Volvo. Data on alternatives are given in Table 2, and all data were obtained from paver vendors and catalogs.

Table 2. Description of alternatives.

	C1	C2	C3	C4	C5	C6	C7	C8
A1—Volvo P2820D ABG	20	4.5	17.9	72	9	55.4	caterpillars	300
A2—P2870D ABG	20	16	17.9	72	9	55.4	wheels	300
A3—AP355F	25	11	20	80	9	55	caterpillars	260
A4—AP300F	30	16	20	80	9	55	wheels	260
A5—SUPER 1000	18	4.5	21	85	10	55	caterpillars	300
A6—SUPER 1003	18	20	22	85	10	55	wheels	300
A7—SUPER 1300	30	4.5	25	80	10	74.4	caterpillars	300
A8—SUPER 1300-3	30	4.5	29	85	10	74.4	caterpillars	300
A9—SUPER 1303	30	20	25	80	10	74.4	wheels	300
A10—SUPER 1303-3	30	20	29.4	85	10	74.4	wheels	300

	C9	C10	C11	C12	C13	C14	C15	C16
A1—Volvo P2820D ABG	4.5	Up to 20	5300/3240/3995	8155	250	330 with one conveyor; 230-with two conveyors	EU Stage V	148,000
A2—P2870D ABG	4.5	to 25	5320/3240/3995	7635	110	330 with one conveyor; 230-with two conveyors	EU Stage V	152,000
A3—AP355F	4.6	to 20	5047/3180/3415	7300	110	406	EU Stage IIIB, U.S. EPA Tier 4 Final,	255,000
A4—AP300F	4	to 30	4870/3180/3340	6600	110	406	EU Stage IIIB, US EPA Tier 4 Final	230,000
A5—SUPER 1000	3.9	to 15	4950/3350/3515	10,250	110	270	EU Stage IIIa, US EPA Tier 3	165,000
A6—SUPER 1003	3.9	to 15	4950/3265/3515	10,000	105	230	EU Stage IIIa, US EPA Tier 3	165,000
A7—SUPER 1300	5	to 25	4950/3350/3500	10,600	105	350	EU Stage IIIa, US EPA Tier 3	180,000
A8—SUPER 1300-3	5	to 25	4950/3350/3500	11,400	110	350	EU Stage IIIa, US EPA Tier 3	180,000
A9—SUPER 1303	4.5	to 25	4950/3265/3500	10,200	110	250	EU Stage IIIa, US EPA Tier 3	185,000
A10 -SUPER 1303-3	4.5	to 25	4950/3265/3500	11,100	100	250	EU Stage IIIa, US EPA Tier 3	185,000

4.3. Definition of Criteria

The set of criteria on the basis of which the evaluation of alternatives was carried out was defined taking into account the opinion and skills of experts and considering the following literature [36–38].

The criteria used to evaluate the pavers are

Group 1: Speed criteria with sub-criteria included: C1—Asphalting speed, C2—Transport speed, C3—Conveyor speed, C4—Drill speed.

Group 2: Technical and technological criteria: C5—Tank capacity, C6—Engine power, C7—Type (wheels/caterpillars), C8—Drill diameter.

Group 3: Criteria related to dimensions: C9—Asphalting width, C10—Asphalt installation thickness, C11—The dimensions of pavers, C12—The weight of pavers.

Group 4: Common criteria that includes sub-criteria related to environmental protection, exploitation and economy: C13—Fuel tank—capacity, C14—Theoretical performance, C15—Gas emissions, C16—The purchase price.

5. Intelligent MCDM Model Based on D and Z Numbers for Paver Selection

In this section of the paper, the calculation of the developed fuzzy MCDM model for paver selection using Z numbers is presented. The weighting coefficients obtained using the IMF D-SWARA method are as follows:

$$\begin{array}{c} C1 = (0.09, 0.09, 0.10) \\ C2 = (0.07, 0.08, 0.08) \\ C3 = (0.05, 0.06, 0.07) \\ C4 = (0.04, 0.05, 0.05) \end{array}, \begin{array}{c} C5 = (0.03, 0.04, 0.05) \\ C6 = (0.06, 0.07, 0.08) \\ C7 = (0.06, 0.07, 0.08) \\ C8 = (0.03, 0.03, 0.04) \end{array},$$

$$\begin{array}{c} C9 = (0.09, 0.10, 0.10) \\ C10 = (0.07, 0.07, 0.08) \\ C11 = (0.06, 0.06, 0.07) \\ C12 = (0.04, 0.05, 0.06) \end{array}, \begin{array}{c} C13 = (0.04, 0.05, 0.06) \\ C14 = (0.06, 0.07, 0.07) \\ C15 = (0.03, 0.04, 0.04) \\ C16 = (0.07, 0.07, 0.08) \end{array}$$

In the next section of the paper, the new Fuzzy ARAS-Z method was applied in order to evaluate and rank 10 potential solutions previously defined. First, the evaluation of all alternatives is presented using the previously defined linguistic scale and using Z numbers. Table 3 shows the ratings of the pavers given by the first expert out of a total of four experts who participated in the group decision-making.

Table 3. Evaluation of pavers for lower road categories using Z numbers by E1.

E1	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$
	C1		C2		C3		C4		C5		C6		C7		C8	
A1	G	VH	M	VH	MG	H	G	VH	VG	H	G	H	G	VH	VG	H
A2	G	VH	VG	H	MG	H	G	VH	VG	H	G	H	VG	VH	VG	H
A3	VG	H	G	VH	MG	VH	VG	VH	VG	H	G	H	G	VH	G	H
A4	EG	H	VG	H	MG	VH	VG	VH	VG	H	G	H	VG	VH	G	H
A5	G	H	M	VH	G	H	EG	VH	VG	VH	G	H	G	VH	VG	H
A6	G	H	EG	H	G	VH	EG	VH	VG	VH	VG	VH	VG	VH	VG	H
A7	EG	H	M	VH	VG	H	VG	VH	VG	VH	VG	VH	G	VH	VG	H
A8	EG	H	M	VH	EG	H	EG	VH	VG	VH	VG	VH	G	VH	VG	H
A9	EG	H	EG	H	VG	H	VG	VH	VG	VH	VG	VH	VG	VH	VG	H
A10	EG	H	EG	H	EG	VH	EG	VH	VG	VH	VG	VH	VG	VH	VG	H
	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$	$\widetilde{A}$	$\widetilde{B}$
E1	C9		C10		C11		C12		C13		C14		C15		C16	
A1	VG	H	VG	H	VG	VH	G	VH	EG	VH	VG	H	EG	VH	EG	VH
A2	VG	H	VG	VH	VG	VH	G	H	G	VH	VG	H	EG	VH	EG	H
A3	VG	VH	VG	H	VG	H	G	H	G	VH	EG	VH	VG	VH	MP	H
A4	G	VH	EG	VH	G	H	M	VH	G	VH	EG	VH	VG	VH	M	H
A5	G	H	G	VH	G	VH	VG	H	G	VH	G	VH	VG	H	G	VH
A6	G	H	G	VH	G	VH	VG	M	G	H	G	M	VG	H	G	VH
A7	EG	VH	VG	VH	G	VH	VG	VH	G	H	VG	VH	VG	H	G	H
A8	EG	VH	VG	VH	G	VH	EG	VH	G	VH	VG	VH	VG	H	G	H
A9	VG	H	VG	VH	G	VH	VG	H	G	VH	G	H	VG	H	G	M
A10	VG	H	VG	VH	G	VH	EG	H	G	M	G	H	VG	H	G	M

The next step involves converting Z numbers into TFN for each expert separately, and then applying the Fuzzy Bonferroni operator to obtain the initial fuzzy decision matrix. E.g., for A1, according to the first expert, an estimate with Z number $\widetilde{A}$ = (G) and $\widetilde{B}$ = VH has been given, which represents TFN (5, 7, 7) for $\widetilde{A}$ and (0.8, 1, 1) for $\widetilde{B}$.

Then, α = 0.933 and by applying Equation (5), the converted TFN (4.86, 6.76, 6.76) is obtained as follows $\left(\sqrt{0.933} \times 5, \sqrt{0.933} \times 7, \sqrt{0.933} \times 7\right)$.

The Fuzzy Bonferroni operator is applied as it is given in the example for the first alternative according to the first criterion, i.e., $\widetilde{\psi_{11}}$:

$$FuzzyBO^{p=1,q=1}\{(4.83,6.76,6.76),(4.83,4.83,6.76),(4.83,4.83,6.76),(4.83,6.76,6.76)\} =$$

$$\begin{cases} \omega^{l}_{C_{1(1)}} = \left(\frac{1}{4(4-1)} \sum\limits_{\substack{i,j=1 \\ i \neq j}}^{4} \omega^{lp}_{C_{1(1)}i} \omega^{lq}_{C_{1(1)}j} \right)^{\frac{1}{1+1}} = \left(0.083\left(4.83^1 \cdot 4.83^1 + 4.83^1 \cdot 4.83^1 + \ldots + 4.83^1 \cdot 4.83^1\right)\right)^{\frac{1}{1+1}} = 4.83 \\ \omega^{m}_{C_{1(1)}} = \left(\frac{1}{4(4-1)} \sum\limits_{\substack{i,j=1 \\ i \neq j}}^{4} \omega^{mp}_{C_{1(1)}i} \omega^{mq}_{C_{1(1)}j} \right)^{\frac{1}{1+1}} = \left(0.083\left(6.76^1 \cdot 4.83^1 + 6.76^1 \cdot 4.83^1 + \ldots + 6.76^1 \cdot 4.83^1\right)\right)^{\frac{1}{1+1}} = 5.77 \\ \omega^{u}_{C_{1(1)}} = \left(\frac{1}{4(4-1)} \sum\limits_{\substack{i,j=1 \\ i \neq j}}^{4} \omega^{up}_{C_{1(1)}i} \omega^{uq}_{C_{1(1)}j} \right)^{\frac{1}{1+1}} = \left(0.083\left(6.76^1 \cdot 6.76^1 + 6.76^1 \cdot 6.76^1 + .. + 6.76^1 \cdot 6.76^1\right)\right)^{\frac{1}{1+1}} = 6.76 \end{cases}$$

After the procedure has been completed, the initial decision matrix for the Fuzzy ARAS-Z method is obtained (Table 4).

Table 4. Initial fuzzy ARAS-Z matrix.

	C1	C2	C3	C4	C5	C6	C7	C8
A1	(4.83, 5.77, 6.76)	(4.83, 5.77, 6.76)	(4.45, 4.87, 6.23)	(4.73, 6.12, 6.49)	(5.17, 6.06, 6.91)	(4.9, 5.78, 6.56)	(4.7, 6.09, 6.59)	(5.75, 6.23, 7.53)
A2	(4.83, 5.77, 6.76)	(4.83, 5.77, 6.76)	(4.45, 4.87, 6.23)	(4.73, 6.12, 6.49)	(5.17, 6.06, 6.91)	(4.9, 5.78, 6.56)	(6.09, 6.59, 7.97)	(5.75, 6.23, 7.53)
A3	(5.78, 6.14, 7.43)	(5.78, 6.14, 7.43)	(4.83, 5.77, 6.76)	(6.76, 6.76, 8.69)	(5.17, 6.06, 6.91)	(4.9, 5.78, 6.56)	(4.7, 6.09, 6.59)	(4.45, 5.3, 6.23)
A4	(6.23, 7.53, 8.02)	(6.23, 7.53, 8.02)	(4.83, 5.77, 6.76)	(6.76, 6.76, 8.69)	(5.17, 6.06, 6.91)	(4.9, 5.78, 6.56)	(6.09, 6.59, 7.97)	(4.45, 5.3, 6.23)
A5	(4.33, 5.17, 6.06)	(4.33, 5.17, 6.06)	(5.17, 6.06, 6.91)	(6.59, 7.97, 8.47)	(5.77, 6.76, 7.71)	(4.9, 5.78, 6.56)	(4.7, 6.09, 6.59)	(5.75, 6.23, 7.53)
A6	(4.33, 5.17, 6.06)	(4.33, 5.17, 6.06)	(5.77, 6.76, 7.71)	(6.41, 8.24, 8.24)	(5.77, 6.76, 7.71)	(6.59, 7.49, 8.47)	(6.09, 6.59, 7.97)	(5.75, 6.23, 7.53)
A7	(6.06, 7.79, 7.79)	(6.06, 7.79, 7.79)	(6.06, 6.91, 7.79)	(6.41, 6.41, 8.24)	(5.77, 6.76, 7.71)	(6.59, 7.49, 8.47)	(4.7, 6.09, 6.59)	(5.75, 6.23, 7.53)
A8	(6.41, 8.24, 8.24)	(6.41, 8.24, 8.24)	(6.41, 8.24, 8.24)	(6.41, 8.24, 8.24)	(5.77, 6.76, 7.71)	(6.59, 7.49, 8.47)	(4.7, 6.09, 6.59)	(5.75, 6.23, 7.53)
A9	(6.41, 8.24, 8.24)	(6.41, 8.24, 8.24)	(6.06, 6.91, 7.79)	(6.76, 6.76, 8.69)	(5.77, 6.76, 7.71)	(6.59, 7.49, 8.47)	(6.09, 6.59, 7.97)	(5.75, 6.23, 7.53)
A10	(6.41, 8.24, 8.24)	(6.41, 8.24, 8.24)	(6.76, 8.69, 8.69)	(6.41, 8.24, 8.24)	(5.77, 6.76, 7.71)	(6.59, 7.49, 8.47)	(6.09, 6.59, 7.97)	(5.75, 6.23, 7.53)
Ao	(6.41, 8.24, 8.24)	(6.06, 7.35, 7.79)	(6.76, 8.69, 8.69)	(6.76, 8.24, 8.69)	(5.77, 6.76, 7.71)	(6.59, 7.49, 8.47)	(6.09, 6.59, 7.97)	(5.75, 6.23, 7.53)

Table 4. *Cont.*

	C9	C10	C11	C12	C13	C14	C15	C16
A1	(5.12, 5.5, 6.69)	(6.23, 7.12, 8.02)	(6.12, 6.49, 7.87)	(4.83, 6.76, 6.76)	(6.76, 7.71, 8.69)	(5.33, 5.78, 6.99)	(6.76, 8.69, 8.69)	(6.76, 8.69, 8.69)
A2	(5.12, 5.5, 6.69)	(6.59, 7.49, 8.47)	(6.12, 6.49, 7.87)	(4.45, 5.75, 6.23)	(4.7, 6.09, 6.59)	(5.33, 5.78, 6.99)	(6.76, 8.69, 8.69)	(6.76, 8.69, 8.69)
A3	(5.95, 6.41, 7.79)	(6.23, 7.12, 8.02)	(5.5, 5.5, 7.07)	(4.45, 5.75, 6.23)	(4.83, 5.77, 6.76)	(6.41, 8.24, 8.24)	(6.59, 7.02, 8.47)	(2.9, 2.9, 4.83)
A4	(4.58, 5.95, 6.41)	(6.59, 8.47, 8.47)	(4.13, 5.33, 5.78)	(3.82, 4.83, 5.77)	(4.7, 6.09, 6.59)	(6.41, 6.84, 8.24)	(6.59, 7.02, 8.47)	(2.9, 4.83, 4.83)
A5	(3.93, 5.12, 5.5)	(4.7, 6.59, 6.59)	(4.58, 6.41, 6.41)	(6.06, 6.06, 7.79)	(4.83, 5.77, 6.76)	(4.7, 6.09, 6.59)	(6.06, 6.06, 7.79)	(4.33, 5.17, 6.06)
A6	(3.93, 5.12, 5.5)	(4.7, 6.59, 6.59)	(4.58, 6.41, 6.41)	(4.95, 4.95, 6.36)	(4.13, 5.33, 5.78)	(3.27, 4.57, 4.57)	(6.06, 6.06, 7.79)	(4.33, 5.17, 6.06)
A7	(6.41, 7.79, 8.24)	(6.59, 7.49, 8.47)	(4.58, 6.41, 6.41)	(6.76, 6.76, 8.69)	(4.33, 5.17, 6.06)	(6.09, 6.59, 7.97)	(6.06, 6.06, 7.79)	(4.33, 5.17, 6.06)
A8	(6.41, 7.79, 8.24)	(6.59, 7.49, 8.47)	(4.58, 6.41, 6.41)	(6.76, 8.69, 8.69)	(4.7, 6.09, 6.59)	(6.09, 6.59, 7.97)	(6.06, 6.06, 7.79)	(4.33, 5.17, 6.06)
A9	(5.12, 5.5, 6.69)	(6.59, 7.49, 8.47)	(4.58, 6.41, 6.41)	(5.78, 6.14, 7.43)	(4.83, 5.77, 6.76)	(3.93, 5.5, 5.5)	(6.06, 6.06, 7.79)	(4.33, 5.17, 6.06)
A10	(5.12, 5.5, 6.69)	(6.59, 7.49, 8.47)	(4.58, 6.41, 6.41)	(6.06, 7.79, 7.79)	(3.93, 4.64, 5.5)	(3.93, 5.5, 5.5)	(6.06, 6.06, 7.79)	(4.33, 5.17, 6.06)
Ao	(6.41, 7.79, 8.24)	(6.59, 8.47, 8.47)	(6.12, 6.49, 7.87)	(6.76, 8.69, 8.69)	(6.76, 7.71, 8.69)	(6.41, 8.24, 8.24)	(6.76, 8.69, 8.69)	(6.76, 8.69, 8.69)

After calculating the fuzzy initial decision matrix and defining the optimal alternative, the procedure of normalization was started. It is important to note that all criteria were modeled as beneficial, because the participants in the group decision-making assigned the highest marks to the best features using a previously defined scale. In this way, the transformation of cost into benefit criteria was performed, and only Equation (10) was applied in the normalization procedure. An example of the normalization procedure is as follows:

$\widetilde{\varsigma_{11}} = \left(\frac{4.83}{81.85}, \frac{5.77}{76.31}, \frac{6.76}{62.03}\right) = (0.06, 0.08, 0.11)$, and the complete normalized fuzzy matrix is shown in Table 5.

Table 5. Normalized matrix in the Fuzzy ARAS-Z method.

	C1	C2	C3	C4
A1	(0.06, 0.08, 0.11)	(0.04, 0.06, 0.1)	(0.05, 0.07, 0.1)	(0.05, 0.08, 0.09)
A2	(0.06, 0.08, 0.11)	(0.07, 0.09, 0.14)	(0.05, 0.07, 0.1)	(0.05, 0.08, 0.09)
A3	(0.07, 0.08, 0.12)	(0.05, 0.08, 0.11)	(0.06, 0.08, 0.11)	(0.08, 0.08, 0.13)
A4	(0.08, 0.1, 0.13)	(0.08, 0.1, 0.15)	(0.06, 0.08, 0.11)	(0.08, 0.08, 0.13)
A5	(0.05, 0.07, 0.1)	(0.04, 0.06, 0.1)	(0.06, 0.08, 0.11)	(0.07, 0.1, 0.12)
A6	(0.05, 0.07, 0.1)	(0.09, 0.12, 0.15)	(0.07, 0.09, 0.13)	(0.07, 0.1, 0.12)
A7	(0.07, 0.1, 0.13)	(0.04, 0.06, 0.1)	(0.07, 0.09, 0.13)	(0.07, 0.08, 0.12)
A8	(0.08, 0.11, 0.13)	(0.04, 0.06, 0.1)	(0.08, 0.11, 0.13)	(0.07, 0.1, 0.12)
A9	(0.08, 0.11, 0.13)	(0.09, 0.12, 0.15)	(0.07, 0.09, 0.13)	(0.08, 0.08, 0.13)
A10	(0.08, 0.11, 0.13)	(0.09, 0.12, 0.15)	(0.08, 0.12, 0.14)	(0.07, 0.1, 0.12)
Ao	(0.08, 0.11, 0.13)	(0.09, 0.12, 0.15)	(0.08, 0.12, 0.14)	(0.08, 0.1, 0.13)

Table 5. *Cont.*

	C5	C6	C7	C8
A1	(0.06, 0.08, 0.11)	(0.06, 0.08, 0.1)	(0.06, 0.09, 0.11)	(0.07, 0.09, 0.12)
A2	(0.06, 0.08, 0.11)	(0.06, 0.08, 0.1)	(0.08, 0.09, 0.13)	(0.07, 0.09, 0.12)
A3	(0.06, 0.08, 0.11)	(0.06, 0.08, 0.1)	(0.06, 0.09, 0.11)	(0.06, 0.08, 0.1)
A4	(0.06, 0.08, 0.11)	(0.06, 0.08, 0.1)	(0.08, 0.09, 0.13)	(0.06, 0.08, 0.1)
A5	(0.07, 0.09, 0.13)	(0.06, 0.08, 0.1)	(0.06, 0.09, 0.11)	(0.07, 0.09, 0.12)
A6	(0.07, 0.09, 0.13)	(0.08, 0.1, 0.13)	(0.08, 0.09, 0.13)	(0.07, 0.09, 0.12)
A7	(0.07, 0.09, 0.13)	(0.08, 0.1, 0.13)	(0.06, 0.09, 0.11)	(0.07, 0.09, 0.12)
A8	(0.07, 0.09, 0.13)	(0.08, 0.1, 0.13)	(0.06, 0.09, 0.11)	(0.07, 0.09, 0.12)
A9	(0.07, 0.09, 0.13)	(0.08, 0.1, 0.13)	(0.08, 0.09, 0.13)	(0.07, 0.09, 0.12)
A10	(0.07, 0.09, 0.13)	(0.08, 0.1, 0.13)	(0.08, 0.09, 0.13)	(0.07, 0.09, 0.12)
Ao	(0.07, 0.09, 0.13)	(0.08, 0.1, 0.13)	(0.08, 0.09, 0.13)	(0.07, 0.09, 0.12)
	C9	C10	C11	C12
A1	(0.07, 0.08, 0.12)	(0.07, 0.09, 0.12)	(0.08, 0.09, 0.14)	(0.06, 0.09, 0.11)
A2	(0.07, 0.08, 0.12)	(0.07, 0.09, 0.12)	(0.08, 0.09, 0.14)	(0.06, 0.08, 0.1)
A3	(0.08, 0.09, 0.13)	(0.07, 0.09, 0.12)	(0.07, 0.08, 0.13)	(0.06, 0.08, 0.1)
A4	(0.06, 0.09, 0.11)	(0.07, 0.1, 0.12)	(0.06, 0.08, 0.1)	(0.05, 0.07, 0.1)
A5	(0.05, 0.08, 0.09)	(0.05, 0.08, 0.1)	(0.06, 0.09, 0.12)	(0.08, 0.08, 0.13)
A6	(0.05, 0.08, 0.09)	(0.05, 0.08, 0.1)	(0.06, 0.09, 0.12)	(0.06, 0.07, 0.1)
A7	(0.08, 0.11, 0.14)	(0.07, 0.09, 0.12)	(0.06, 0.09, 0.12)	(0.08, 0.09, 0.14)
A8	(0.08, 0.11, 0.14)	(0.07, 0.09, 0.12)	(0.06, 0.09, 0.12)	(0.08, 0.12, 0.14)
A9	(0.07, 0.08, 0.12)	(0.07, 0.09, 0.12)	(0.06, 0.09, 0.12)	(0.07, 0.09, 0.12)
A10	(0.07, 0.08, 0.12)	(0.07, 0.09, 0.12)	(0.06, 0.09, 0.12)	(0.08, 0.11, 0.13)
Ao	(0.08, 0.11, 0.14)	(0.07, 0.1, 0.12)	(0.08, 0.09, 0.14)	(0.08, 0.12, 0.14)
	C13	C14	C15	C16
A1	(0.09, 0.12, 0.16)	(0.07, 0.08, 0.12)	(0.08, 0.11, 0.12)	(0.09, 0.13, 0.17)
A2	(0.06, 0.09, 0.12)	(0.07, 0.08, 0.12)	(0.08, 0.11, 0.12)	(0.09, 0.13, 0.17)
A3	(0.06, 0.09, 0.12)	(0.08, 0.12, 0.14)	(0.07, 0.09, 0.12)	(0.04, 0.04, 0.09)
A4	(0.06, 0.09, 0.12)	(0.08, 0.1, 0.14)	(0.07, 0.09, 0.12)	(0.04, 0.07, 0.09)
A5	(0.06, 0.09, 0.12)	(0.06, 0.09, 0.11)	(0.07, 0.08, 0.11)	(0.06, 0.08, 0.12)
A6	(0.06, 0.08, 0.11)	(0.04, 0.07, 0.08)	(0.07, 0.08, 0.11)	(0.06, 0.08, 0.12)
A7	(0.06, 0.08, 0.11)	(0.08, 0.09, 0.14)	(0.07, 0.08, 0.11)	(0.06, 0.08, 0.12)
A8	(0.06, 0.09, 0.12)	(0.08, 0.09, 0.14)	(0.07, 0.08, 0.11)	(0.06, 0.08, 0.12)
A9	(0.06, 0.09, 0.12)	(0.05, 0.08, 0.09)	(0.07, 0.08, 0.11)	(0.06, 0.08, 0.12)
A10	(0.05, 0.07, 0.1)	(0.05, 0.08, 0.09)	(0.07, 0.08, 0.11)	(0.06, 0.08, 0.12)
Ao	(0.09, 0.12, 0.16)	(0.08, 0.12, 0.14)	(0.08, 0.11, 0.12)	(0.09, 0.13, 0.17)

In the next step, the fuzzy normalized matrix was weighted by applying Equation (12), the optimality function was determined by Equation (13), the utility degree of alternatives was defined by Equation (14), and the final results are shown in Table 6.

Table 6. Results of integrated IMF D-SWARA and Fuzzy ARAS-Z model.

	Oi	***Ai***	**Crisp *Ai***	**Rank**
A1	(0.06, 0.09, 0.13)	(0.38, 0.80, 1.80)	0.895	7
A2	(0.06, 0.09, 0.13)	(0.40, 0.81, 1.84)	0.911	5
A3	(0.06, 0.08, 0.13)	(0.38, 0.76, 1.78)	0.864	9
A4	(0.06, 0.09, 0.13)	(0.38, 0.80, 1.79)	0.895	6
A5	(0.05, 0.08, 0.12)	(0.34, 0.74, 1.67)	0.829	10
A6	(0.06, 0.09, 0.13)	(0.37, 0.78, 1.73)	0.872	8
A7	(0.06, 0.09, 0.14)	(0.40, 0.83, 1.87)	0.932	4
A8	(0.06, 0.10, 0.14)	(0.41, 0.87, 1.89)	0.965	1
A9	(0.06, 0.09, 0.14)	(0.41, 0.84, 1.89)	0.945	3
A10	(0.06, 0.10, 0.14)	(0.41, 0.87, 1.89)	0.960	2
So	(0.07, 0.11, 0.15)			

The values of A_i for the first alternative are obtained by applying Equation (14) as follows:

$$\widetilde{A}_1 = \frac{\widetilde{O}_1}{\widetilde{O}_o} = \left(\frac{0.06}{0.15}, \frac{0.09}{0.11}, \frac{0.13}{0.07}\right) = (0.38, 0.80, 1.80) \quad (15)$$

The final results show that the alternative A8 has the best characteristics according to the considered set of criteria for the lower category of roads, and it is the paver SUPER 1300-3. The overall ranking of alternatives is A8 > A10 > A9 > A7 > A2 > A4 > A1 > A6 > A3 > A5.

6. Tests of Verification

6.1. Comparative Analysis

Decision-making is a specific form of activity [39] and many MCDM methods apply it to numerous decision problems from different disciplines [40,41]. In this part of the verification of the results obtained, a comparative analysis with four other fuzzy MCDM methods based on Z numbers was created. The Fuzzy MABAC-Z method [42,43], Fuzzy WASPAS-Z [44], Fuzzy MARCOS-Z [45,46] and Fuzzy SAW-Z method [45] were applied. The results of this analysis are shown in Figure 2, both in terms of ranks and in terms of the value of pavers.

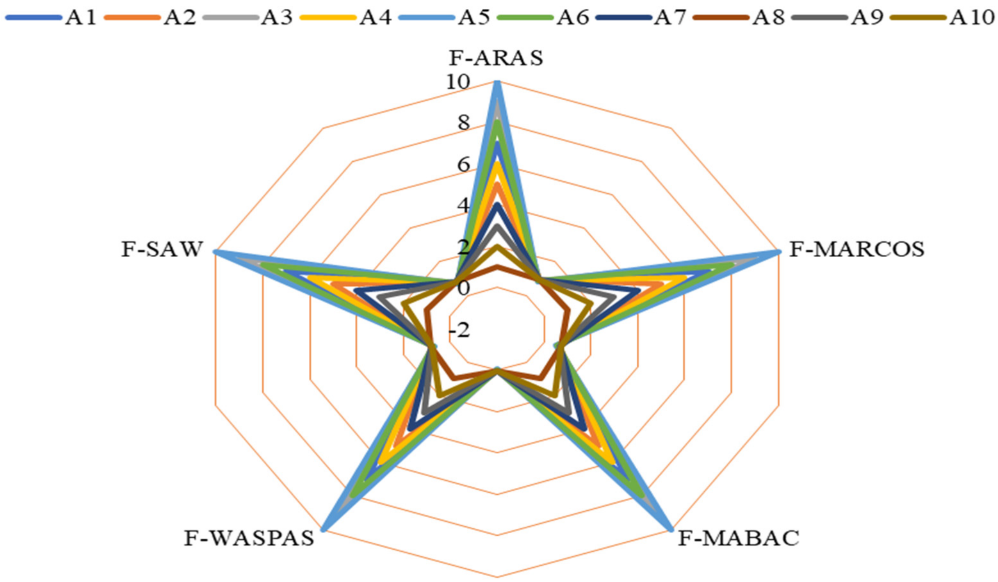

Figure 2. Results of comparative analysis.

The results of the first verification test show that the proposed model is completely stable, because there is no difference in the ranks of the alternatives. It is an interesting fact that in all methods except Fuzzy MARCOS-Z there is a slight difference in the values of all alternatives, but there are no changes in the ranks.

6.2. The Influence of Changing the Size of the Initial Fuzzy Decision Matrix

In the second verification test, the influence of the size of the initial fuzzy decision matrix on the final results was determined, i.e., the dynamic influence of the decision matrix was tested. A total of nine sets was formed, which implies that the alternative with the worst performance is eliminated from the IMF D-SWARA-Fuzzy ARAS-Z model. The procedure is repeated until the initial matrix is reduced to one alternative. The results of the dynamic influence of the initial matrix are shown in Figure 3 along with the ranks and values of the pavers.

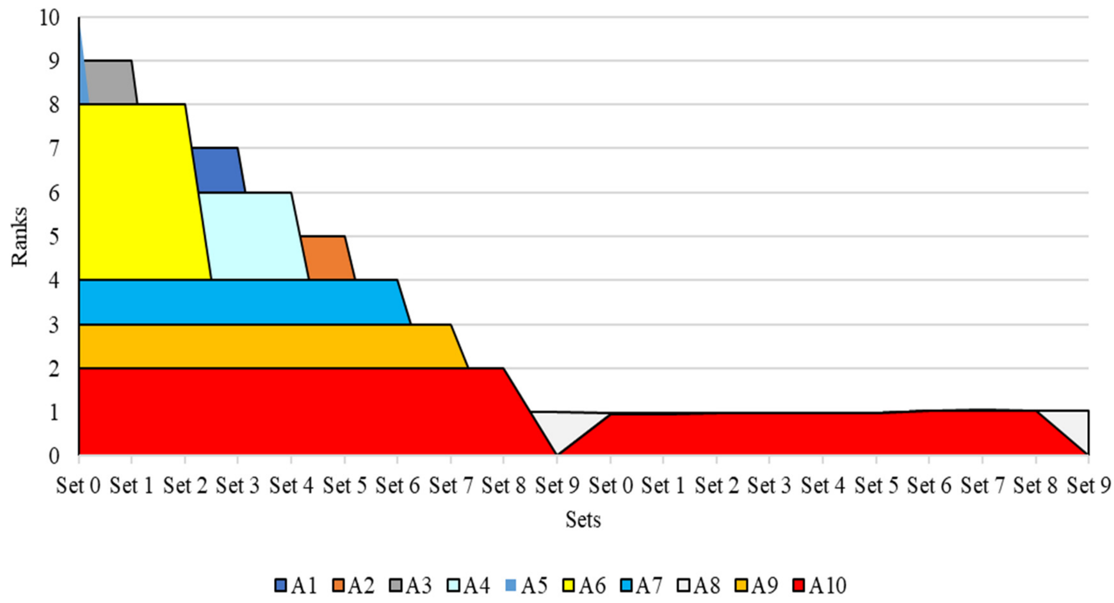

Figure 3. Results of the impact of the initial matrix size.

After changing the size of the initial decision matrix in the Fuzzy ARAS-Z model, it can be seen that the model is still stable and that the alternatives retain their positions from the original model. The only difference occurs in the first set when alternative A5 is eliminated, with alternatives A1 and A4 rotating their positions (seven and six). However, in the following scenario, when alternative A3 is also eliminated, they return to their original positions, which is, in a way, very difficult to explain. Mainly, in this verification test which includes different normalization procedures, additional stability of the developed model was also demonstrated.

6.3. Impact of Changing the Normalization Procedure

In this section of the paper, the reproduction of the Fuzzy ARAS model based on Z numbers was performed with a change in the normalization procedure that can be found in the paper [47]. In the first case, using Equation (15), the linear normalization used in the fuzzy MARCOS method was defined [48,49]; in the second case, using Equation (16), the maximum linear normalization was defined [49]. The third scenario implies the minimum linear normalization [49] represented by Equation (17), while the fourth scenario is the nonlinear normalization procedure [50] represented by Equation (18).

$$\widetilde{n}_{ij} = \left(n_{ij}^{l}, n_{ij}^{m}, n_{ij}^{u}\right) = \left(\frac{x_{ij}^{l}}{x_{id}^{u}}, \frac{x_{ij}^{m}}{x_{id}^{u}}, \frac{x_{ij}^{u}}{x_{id}^{u}}\right) \; if\, j \in B \tag{16}$$

$$\widetilde{n}_{ij} = \left(n_{ij}^{l}, n_{ij}^{m}, n_{ij}^{u}\right) = \left(\frac{x_{ij}^{l}}{\max x^{u}}, \frac{x_{ij}^{m}}{\max x^{m}}, \frac{x_{ij}^{u}}{\max x^{l}}\right) \; if\, j \in B \tag{17}$$

$$\widetilde{n}_{ij} = \left(n_{ij}^{l}, n_{ij}^{m}, n_{ij}^{u}\right) = \left(\left(\frac{x_{ij}^{l}}{\max x^{u}}\right)^{2}, \left(\frac{x_{ij}^{m}}{\max x^{m}}\right)^{2}, \left(\frac{x_{ij}^{u}}{\max x^{l}}\right)^{2}\right) \; if\, j \in B \tag{18}$$

$$\widetilde{n}_{ij} = \left(n_{ij}^{l}, n_{ij}^{m}, n_{ij}^{u}\right) = 1 - \left(\frac{\min x_{ij}^{l}}{x_{ij}^{u}}, \frac{\min x_{ij}^{m}}{x_{ij}^{m}}, \frac{\min x_{ij}^{u}}{x_{ij}^{l}}\right) \; if\, j \in B \tag{19}$$

The results of this analysis are presented in Figure 4.

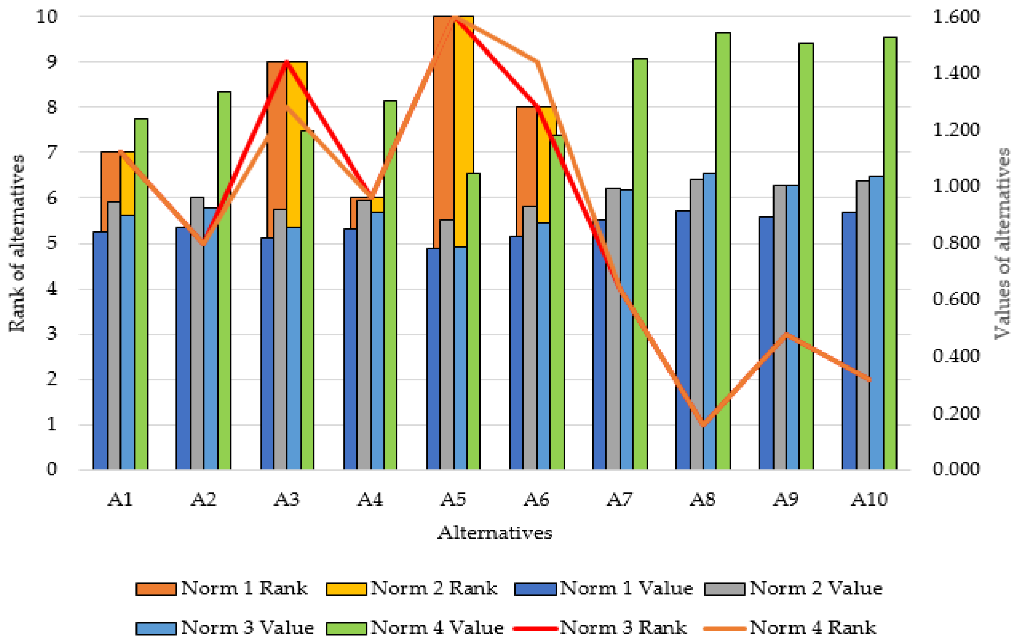

Figure 4. The influence of the normalization procedure on the results.

After applying different normalization procedures in the Fuzzy ARAS-Z model, it can be seen that the model is still stable and that the alternatives keep their positions from the original model. The only difference occurs in the procedure of applying nonlinear normalization, whereby alternatives A3 and A6 rotate their positions (nine and eight). Mainly, in this verification test which includes different normalization procedures, additional stability of the developed model has also been demonstrated.

7. Conclusions

In order to adequately use road infrastructure and enable the efficiency of road capacity [51], it is necessary to pay attention to construction materials and the quality of construction machinery. It is one of these segments that is the subject of the research and selection of adequate mechanization for infrastructure construction for roads with an asphalt width of up to five meters, which represents a lower category of roads. As part of the research, data for 10 different pavers representing potential solutions were collected and evaluated based on 16 criteria. In order to enable precision in the application of the intelligent Fuzzy MCDM model, a hierarchical structure with an equal number of elements on the second level was created. Due to this and the application of the strong IMF D-SWARA model, the precise weights of the criteria have been calculated, eliminating the possibility that one of the criteria has an unjustifiably high value, which is the case in other studies that apply an unbalanced hierarchical structure.

The most important contribution of the research from the methodological and scientific aspect involves the development of a novel original Fuzzy ARAS-Z model that has been used for the evaluation and selection of pavers. In this way, the emphasis is put on the novelty of the study, while the professional contribution is reflected in the selection of adequate construction machinery, i.e., pavers.

The results show the following ranking of the alternatives: A8 > A10 > A9 > A7 > A2 > A4 > A1 > A6 > A3 > A5. In order to verify the results obtained, three validity tests were applied which, with negligible deviations, showed an extremely high level of stability of the original IMF D-SWARA-Fuzzy ARAS-Z model.

Considering that this is a multistage project, future research should be directed towards the selection of pavers for highways in order to complete the project of evaluation and selection of adequate mechanization depending on the categories of roads in Serbia. In addition, more decision-makers can be included to access the conditions of the evaluation model and their performances. The same model can be applied in any other equipment decision-making approach in order to ensure the sustainability of construction road infrastructure. In addition, the direction of further research can be reflected through the development of new similar models and applications in civil engineering as integration of fuzzy rough theories.

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