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Comparison of Aggregation Operators in the Group Decision-Making Process: A Real Case Study of Location Selection Problem

Goran Petrović [1], Jelena Mihajlović [1], Danijel Marković [1], Sarfaraz Hashemkhani Zolfani [2,*] and Miloš Madić [1]

1 Faculty of Mechanical Engineering in Niš, University of Niš, 18000 Niš, Serbia; goran.petrovic@masfak.ni.ac.rs (G.P.); jelena.mihajlovic@masfak.ni.ac.rs (J.M.); danijel.markovic@masfak.ni.ac.rs (D.M.); milos.madic@masfak.ni.ac.rs (M.M.)
2 School of Engineering, Universidad Catolica del Norte, Larrondo 1281, Coquimbo 1780000, Chile
* Correspondence: sarfaraz.hashemkhani@ucn.cl

Abstract: Aggregation methods in group decision-making refer to techniques used to combine the individual preferences, opinions, or judgments of group members into a collective decision. Each aggregation method has its advantages and disadvantages, and the best method to use depends on the specific situation and the goals of the decision-making process. In certain cases, final rankings of alternatives in the decision-making process may depend on the way of combining different attitudes. The focus of this paper is the application and comparative analysis of the aggregation operators, specifically, arithmetic mean (AM), geometric mean (GM), and Dombi Bonferroni mean (DBM), to the process of criteria weights determination in a fuzzy environment. The criteria weights are determined using Fuzzy Multi-Criteria Decision-Making (F-MCDM) methods, such as Fuzzy Analytic Hierarchy Process (F-AHP), Fuzzy Pivot Pairwise Relative Criteria Importance Assessment (F-PIPRECIA), and Fuzzy Full Consistency Method (F-FUCOM), while the final alternative ranking is obtained by Fuzzy Weighted Aggregated Sum Product Assessment (F-WASPAS). A comparison of aggregation operators is done for the real case of location selection problem for a used motor oil transfer station in the regional center of Southern and Eastern Serbia, the city of Niš. The results obtained in this study showed that the views of different experts and application of a certain aggregation approach may have a significant impact on the values of criteria weight coefficients and further on the final ranking of alternatives. This paper is expected to stimulate future research into the impact of aggregation methods on final rankings in the decision-making process, especially in the field of waste management.

Keywords: aggregation operators; fuzzy MCDM; group decisioning; location selection; logistic system; ranking of alternatives; transfer station; used motor oil

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1. Introduction

The most critical problem in the strategic planning of a logistic system is the location selection problem, which is mostly based on the criteria of minimum transport costs (transportation price, travel distance, duration of transportation operations, etc.). In general, location selection refers to the tasks of determining the location of an object or determining the total number of objects in which logistics services are performed, while location theory refers to the methods used to solve such tasks.

The location selection problem represents a facility location problem which is an optimization problem that determines the best location for facilities of various types to be placed based on specific demands and desires of decision-makers [1]. The location selection within a logistic system, e.g., distribution centers [2,3], different types of warehouses and storages [4], cargo and passengers' terminals [5], parking lots [6], transport centers, bus or railway stations, schools, gas stations, health centers, sanitary landfills for waste disposal, and many others, belongs to very complex planning problems. Thus, it could be classified differently depending on the classification criteria.

The location selection problems could be assessed with numerous models that can be found in the literature, such as the set covering location model, maximal covering location problem, p dispersion problem, p center problem, p median problem, and hub location problem. In addition, various methods have the same goal of solving the location selection problem. Those methods could be conventional optimization methods (mathematical programming methods), global optimization methods (heuristic and metaheuristic methods), simulation methods (based on computer simulations), and hybrid methods (different combinations of previously mentioned methods).

The location selection problem, in general, is a complex problem of many confronting criteria (political, economic, infrastructural, and environmental criteria, as well as a development strategy, logistic costs, services, etc.) and possible alternative solutions. Thus, this problem could be observed as a multi-criteria decision-making (MCDM) problem. The application of a widely spread MCDM methodology for solving location selection problems has been extensively studied by researchers for many years, and there have been many studies regarding the efficacy of the implementation of different methods and approaches. Some classical methods have been applied, but nowadays, more enhanced approaches emerge in the way of fuzzy MCDM and hybrid MCDM variants.

Generally, the advantages of MCDM methods are a transparent and relatively simple way of formulating optimization models (especially in cases of a larger number of criteria), as well as the fact that the decision rules, which are generated by different MCDM methods, are simple and have a clear algorithmic structure. On the other hand, one should also bear in mind the fact that decision rules generated for the same decision-making problem by different MCDM methods may give different results. Another disadvantage, especially compared to classical optimization approaches, is that the set of possible solutions is finite, known in advance, and in essence, highly dependent on the decision maker.

Therefore, a summary table is given (Table 1) indicating the most important recent studies and their pros and cons, bearing in mind that the presented table refers only to the field of waste management.

Table 1. Summary table of some important recent studies for solving the location selection problems using MCDM methodology.

Author(s), Year, Reference	The Problem Solved	Used Methods	Aggregation Approach	Pros and Cons
Kurbatova A.; Abu-Qdais H.A., 2020, [7]	Selection of waste to energy technology for a mega city	AHP	AM	Pros: - sensitivity analysis of alternatives ranking based on different scenarios of criteria weights. Cons: - the weights of criteria are determined using only one MCDM methodological approach (AHP), - application of traditional AHP (it does not consider uncertainty in the decision-making process).
Mallick J., 2021, [8]	Development of an integrated framework with a focus on structuring the decision-making process for the municipal solid waste landfill suitability site map	- GIS - F-AHP	F-GM	Pros: - application of the F-AHP method instead of traditional AHP (phenomenon of rank reversal), - a post-suitability field investigation to consider the final landfill sites is performed, - sensitivity analysis. Cons: - the weights of criteria are determined using only one MCDM methodological approach (F-AHP).

Table 1. *Cont.*

Author(s), Year, Reference	The Problem Solved	Used Methods	Aggregation Approach	Pros and Cons
Sagnak M., Berberoglu Y., Memis I., Yazgan O., 2021, [9]	Development of a framework for identification of sustainable e-waste location collection centers	- F-BWM - F-TOPSIS	LSGDM	Pros: - F-BWM—smaller number of pairwise comparisons than in other methods, - thirty experts carried out pairwise comparisons. - application of fuzzy MCDM methodology. Cons: - the weights of criteria are determined using only one MCDM methodological approach (F-BWM), - unclear how LSGDM is implemented.
Rahimi S., Hafezalkotob A., Monavari S.M., Hafezalkotob A., Rahimi R., 2019, [10]	Development of a methodology for landfill site selection problem solving (real-world problem—municipal solid waste in city of Mahallat, Iran)	- G-F-BWM - GIS - MULTI-MOORA	G-F-BWM	Pros: - G-F-BWM for weighting criteria is more reliable compared to the other common methods, - consideration of fourteen criteria, Cons: - G-F-BWM—computationally, a very demanding method.
Demircan, B.G.; Yetilmezsoy, K. A, 2023, [11]	Evaluation of four different smart waste management strategies using a hybrid fuzzy MCDM method	- F-AHP - F-TOPSIS	F-GM	Pros: - development of a hybrid fuzzy MCDM approach, - consideration of fifteen sub-criteria belonging to five main criteria, - ten different experts were interviewed, - sensitivity analysis was done to test the consistency of the rankings (eighteen different scenarios), Cons: - the study proposed strategies (alternatives) in a general way, without real-life data and specific city, residential area, or pilot region. - there is no comparison of proposed approach with other similar MCDM approaches.
Torkayesh A.E., Zolfani S.H., Kahvand M., Khazaelpour P., 2021, [12]	Development of novel integrated decision-making model for landfill location selection for the health-care waste system	- BWM - GIS - G-MARCOS	Expert consensus	Pros: - development of novel hybrid MCDM approach in the considered field, - fifteen criteria are identified for sustainable landfill sitting problems, - two sensitivity analysis tests were performed to check the reliability and robustness of the results, Cons: - no information about method that was used for reaching the consensus of experts in the weight determination process, - application of traditional BWM.
Zhang C., Hu Q., Zeng S., Su W. 2021, [13]	Development of an effective PFIOWLAD (Pythagorean fuzzy induced ordered weighted logarithmic averaging distance)-MCDM model for solving the site assessment issue of a household waste processing plant in Shanghai	- Normal distribution-based method, - PFIOWLAD operator	PFIOWLAD operator	Pros: - development of an effective PFIOWLAD-MCDM model, - dealing with uncertain information in the decision-making process, - expert's weighting vector—according to the professional degree and authority, - comparative analysis of different operators. Cons: - PFIOWLAD operator—computationally, a very demanding, - insufficiently reasonable and realistic method of criteria weight determination.

Table 1. *Cont.*

Author(s), Year, Reference	The Problem Solved	Used Methods	Aggregation Approach	Pros and Cons
Karagoz S., Deveci M., Simic V., Aydin N., 2021, [14]	Development of an extension of the ARAS method based on a novel interval type-2 fuzzy set for solving the location selection problem of a recycling facility in Turkey	IT2F-ARAS method	AM	Pros: - fifteen criteria are evaluated, - the implementation procedure is not complex and provides less computational time, - comparison of existing methods with the proposed model, Cons: - unclear approach for determination of criteria weights by each expert.

Acronyms: Analytical Hierarchy Approach (AHP), Fuzzy Analytical Hierarchy Approach (F-AHP), Best–Worst Method (BWM), Fuzzy Best–Worst Method (F-BWM), Group Fuzzy Best–Worst Method (G-F-BWM), Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (F-TOPSIS), Group fuzzy multi-objective optimization by ratio analysis plus the full multiplicative form (MULTIMOORA), Grey measurement of alternatives and ranking according to compromise solution (G-MARCOS), Interval type-2 fuzzy additive ratio assessment (IT2F-ARAS) method, Pythagorean fuzzy induced ordered weighted logarithmic averaging distance (PFIOWLAD), Geographical Information System (GIS), Arithmetic mean (AM), Fuzzy Geometric Mean (F-GM), Large-scale group decision making (LSGDM).

The results of reference literature analysis showed that along with the increasing application of new, hybrid, and fuzzy approaches, traditional methods still play a significant role in criteria weights determination and generation of decision rules. The application of fuzzy-based MCDM methods makes it possible to handle imprecision and uncertainty during the decision-making process. In addition, fuzzy MCDM methods are able to integrate different types of criteria compared to traditional approaches, because they are able to handle qualitative information and linguistic variables, in addition to numerical data.

A decision-making (DM) process is a process of determining and ranking alternative solutions from multiple options [15,16]. With the enhanced complexity of DM problems, it is hard for individuals to comprehend all major information and give consistent conclusions [17]. Thus, group decision-making (GDM) is introduced. A GDM problem could be observed as a DM problem with multiple possible alternative solutions and a set of decision-makers/experts that evaluate alternative solutions to accomplish a common goal considering their opinions, preferences or judgments [18].

The variety of studies was based on the GDM principles. The tendency is to enhance the DM process by adopting different techniques. Some of them are a consensus model for GDM problems with linguistic interval fuzzy preference relations [18]; a granular multi-criteria GDM [15]; a variable precision diversified attribute multi-granulation fuzzy rough set-based multi-attribute GDM [19]; a hierarchical integration method [20]; collaborative group embedding and decision aggregation based on the attentive influence of individual members [21]; an interval type-2 fuzzy clustering solution [22]; a dynamic programming algorithm-based picture fuzzy clustering approach [17], etc.

GDM problems supported by the MCDM methodology could provide an objective, consistent, reliable, and fast decision-making process for a wide area of expertise. When MCDM supports GDM, some mathematical aggregation operators must be applied to obtain an aggregated decision-making matrix [23]. Some of the widely applied mathematical aggregation operators are arithmetic mean [24], geometric mean [25], Dombi operator [26], Bonferrioni operator [27], Dombi–Bonferrioni operator, Einstein operator [28], Hamacher operator [29], power aggregation operator [30], neutral aggregation operator [31], Heronian aggregation operator [32], combined aggregation operator [33], optimal aggregation operator [34], etc.

Practical applications of the previously mentioned aggregation operators, decision-making under uncertainty, and some hybrid approaches for solving specific problems of group decision-making can be found in the reference literature [35–41]. One can observe an insufficient number of studies which analyze the impact of different aggregation operators on the determination of criteria weights and final ranks of alternatives.

The advantage of using aggregation operators, compared to other methods (Delphi method, brainstorming, majority voting, consensus, etc.), is their objective sublimation of different opinions of experts—decision makers, who may belong to different interest groups. On the other hand, some of these methods can be very mathematically complex, and as such, are not easy to use by people who solve specific decision problems.

Basically, MCDM methods use a defined set of criteria to evaluate possible alternative solutions. Thus, properly defined criteria are an essential step in the process of evaluating alternatives. Inadequately defined criteria and, furthermore, inadequately determined criteria weights could lead to unsteady and unreliable results with many variations, especially in complex problems involving many criteria. On the other hand, numerous studies have shown that no single MCDM method is the best solution for a given decision-making problem, and that a hybrid combination of different theoretical approaches of MCDM methods can provide a more robust and comprehensive decision rule [39].

Motivated by this fact, the main goal of this paper is to show that the application of only one aggregation method (without a deeper analysis of its impact on criteria weights and final ranking of alternatives) is not a good enough approach in the group decision-making process. Based on previously analyzed literature, three well known fuzzy MCDM methods for criteria weights determination: Fuzzy Analytic Hierarchy Process (F-AHP), Fuzzy Pivot Pairwise Relative Criteria Importance Assessment (F-PIPRECIA), Fuzzy Full Consistency Method (F-FUCOM), supported by three fuzzy aggregation operators: arithmetic mean (AM), geometric mean (GM), and Dombi Bonferroni mean (DBM), are chosen for consideration. The final alternative ranking is obtained by the Fuzzy Weighted Aggregated Sum Product Assessment (F-WASPAS) method. MCDM methods for criteria weights determination are chosen because of their significant popularity. Bearing in mind the ultimate goal of this paper, some other methods could have been applied. The only condition for the selection of criteria weight methods was that they are subjective methods, so that the opinions of different experts could be expressed. In addition, for the purpose of this paper, the authors chose three aggregation operators, two of which are mathematically quite simple and generally accepted (AM and GM), while the third is rather more complex, but with numerous studies supporting its application.

The hypothesis of this study is that the application of three different fuzzy aggregation operators, for solving the same decision-making problem according to opinions and attitudes of the same experts, may lead to different solutions. A comparison of aggregation operators will be done for a real case study of a location selection problem for the used motor oil transfer station in the regional center of Southern and Eastern Serbia, the city of Niš.

Hazardous waste management specifically used in motor oil management must include safe, logistically efficient, and cost-effective collection, transportation, and disposal (or recycling) in a highly defined and organized manner [42–44]. To support the process of collection of used motor oils, authorized transfer stations must be formed. The lack of a proper infrastructure threatens the possibility of proper used motor oil disposal and storage.

The transfer station is a temporary facility for waste oil collection and storage. Such stations are used for the selection and transshipment of waste oil before its transport to another facility for storage, treatment, recycling, or disposal. Typically, they are multiple collection centers where multiple collection vehicles can bring different waste types in order of more efficient collection, reduced air emissions, energy use, transport costs, road wear and tear, safer waste handling, and more economical waste hauling.

A vast number of studies deal with waste transfer stations' impact on the environment and healthcare regarding the risks from waste manipulation [45,46] and energy utilization [47]. Some of these studies deal with industrial waste management [48], landfill site selection in general, hazardous wastes site selection and location routing [42,43,49], and waste containers; but the outbreak of the COVID-19 pandemic also initiated research based on medical waste management [50]. In the open literature for waste transfer station locations, one can find applications of the robust optimization model of waste transfer station location considering existing facility adjustment [51]. In addition, a two-stage multi-attribute decision-making model for selecting proper locations was set for urban centers [52]. Moreover, an intuitionistic fuzzy multi-distance-based evaluation for aggregated dynamic decision analysis (IF-DEVADA) was applied to waste disposal location selection [53].

The paper outline is as follows: The applied methods and proposed approach for comparing the fuzzy aggregation operators for group decision-making are presented in Section 2; a real case study—the selection of waste oil transfer station location in the city of Niš—is shown in Section 3; while the obtained results and their discussion are given in Section 4. Finally, Section 5 provides some concluding remarks and potential future research directions.

2. Applied Methods and Proposed Approach

Considering that different DM rules, obtained using different criteria weights, can give a different ranking of alternatives, the aim of this paper is to show how the approach of fuzzy aggregation operators Arithmetic Mean (F-AM), Geometric Mean (F-GM), and Dombi Bonferroni (F-DB) affects the weight coefficients of criteria as well as the ranking of alternatives, in relation to each aggregation operator.

As shown in Figure 1, a group of three experts participated in this case study. They compared each criterion in relation to each subjective fuzzy method: Analytic Hierarchy Process (F-AHP), Fuzzy Pivot Pairwise Relative Criteria Importance Assessment (F-PIPRECIA), and Fuzzy Full Consistency Method (F-FUCOM). The obtained results of the weight coefficients based on these methods were used for further approach. The approach is based on aggregation operators such as F-AM, F-GM, and F-DBM. The results obtained by this methodology were compared, and then, the fuzzy Weighted Aggregated Sum Product Assessment (F-WASPAS) method was applied in relation to each aggregation method for the complete ranking of alternatives. Finally, the obtained results of the complete ranking of alternatives were also compared.

Any decision-making problem can be represented by a decision matrix consisting of m alternatives and n criteria, where x_{ij} stands for the performance of the i-th criterion in relation to the j-th alternative. In this case study, which refers to the waste oil collection station on the territory of the city of Niš, the decision matrix was formed based on the research conducted on the subject for the last three years.

2.1. Multi Criteria Decision Making (MCDM)

Multi-criteria decision-making deals with direct decision-making problems where a solution is chosen from a final, predefined set of potential solutions based on several diverse and often conflicting criteria, which, as a rule, have a different level of importance.

Various implementations of the MCDM model through different tools can be used individually or combined into a hybrid decision network.

Some of the tools used in this work are Fuzzy Analytic Hierarchy Process (F-AHP), Fuzzy Pivot Pairwise Relative Criteria Importance Assessment (F-PIPRECIA), and Fuzzy Full Consistency Method (F-FUCOM).

2.1.1. Fuzzy Analytic Hierarchy Process (F-AHP)

The F-AHP method is used for criteria weight determination. This methodology combines fuzzy logic based on fuzzy triangular numbers and the well-known AHP methodology developed by Saaty [54]. The AHP method is the MCDM method which can be used for the analysis of complex decisions using mathematics and psychology. Thomas L. Saaty developed it in the 1970s, and it has been refined ever since. It consists of three parts: the goal or the problem, possible alternative solutions, and the criteria. This method provides an objective framework for a desired decision by quantifying its criteria and possible alternative solutions and relating all of those elements to the global goal [55,56].

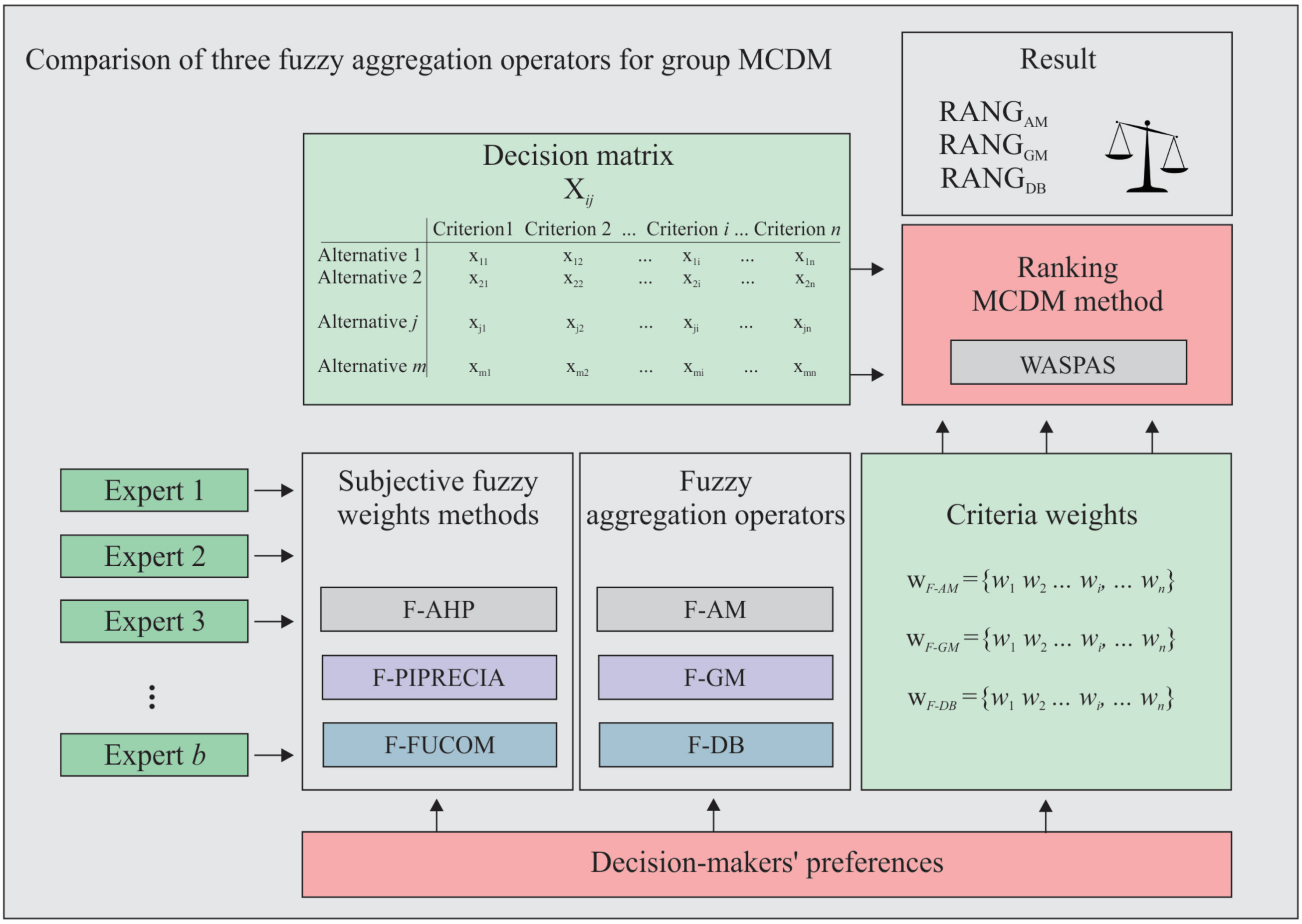

Figure 1. Schematic representation of the proposed approach for a comparison of the fuzzy aggregation operators for group decision-making.

The F-AHP method can eliminate the shortcomings of the classical AHP method. Detailed, step-by-step explanations of the determination of criteria weights by the fuzzy AHP method can be found in referential literature [55–57].

2.1.2. Fuzzy Pivot Pairwise Relative Criteria Importance Assessment (F-PIPRECIA)

The Pivot Pairwise Relative Criteria Importance Assessment (PIPRECIA) method was developed by Stanujkic et al. [58] in 2017. The PIPRECIA method allows the evaluation of criteria without the need to first sort them by significance. This method is suitable for gathering valuable information through questionnaires (qualitative based). Since fuzzy logic is based on the transformation of the qualitative to the quantitative, the method is perfect to combine.

The fuzzy PIPRECIA method was developed by Stević et al. in 2018, consisting of 11 steps. A more detailed framework of the proposed method could be found in referential literature [59–61].

2.1.3. Fuzzy Full Consistency Method (F-FUCOM)

The full consistency method (FUCOM), developed by Pamučar et al. [62], is based on the comparison of criteria by pairs and the validation of results through assessing the range of deviation from maximum consistency. The criteria weights could significantly impact the results obtained by the MCDM methodology. Consequently, a vast number of methods for criteria weights determination have been proposed.

The main goal is to define which criterion has the greatest importance, and therefore the greatest influence on the quality of the DM process. In addition, the goal is to demonstrate the proposed method's applicability and its application's simplicity.

A more detailed framework of the proposed method can be found in [40,63].

2.1.4. Fuzzy Weighted Aggregated Sum Product Assessment (F-WASPAS)

The Weighted Aggregated Sum Product Assessment (WASPAS) method was proposed by Zavadskas et al. [64] in 2012. The WASPAS method combines WSM (Weighted Sum Method) and WPM (Weighted Product Method) using the common optimality criterion, which can be determined based on a linear combination of WSM and WPM criteria. The WSM involves calculating a weighted sum of the criteria scores (the attribute values) for each alternative, while WPM involves calculating a weighted product of the criteria scores for each alternative. The combination of the two methods in the WASPAS method aims to capture the advantages of both methods.

The general characteristic of the WASPAS method is that it enables evaluating and ranking of alternatives with a high degree of reliability.

In previous years, some variations of the traditional WASPAS method, which incorporates uncertainty in the criteria weights and performance ratings, can be found in the literature: WASPAS-G (intended to work with grey numbers), WASPAS-F (fuzzy numbers), and WASPAS-IVIF (interval-valued intuitionistic fuzzy numbers). The F-WASPAS method consists of 6 steps, and a more detailed analysis can be found in [65].

2.2. Aggregation Operators in Group Decision Making

Aggregation operators in group decision-making are mathematical functions used to combine the individual preferences, opinions, or judgments of group members into a collective decision. Aggregation operators calculate the average, total, minimum, or maximum value of the numeric attributes in a collection of objects or the number of objects in a collection. Different aggregation approaches have different assumptions of the data (data types) that can be incorporated into the model. The Arithmetic mean, Geometric mean, and Dombi Bonferroni will be presented and applied in the present study.

2.2.1. Arithmetic Mean

The arithmetic mean, also known as the average, is one of the most used aggregation operators and is represented as an additive mean (it is based on adding and dividing values). The arithmetic mean is defined as being equal to the sum of the numerical values from the dataset, divided by the total number of the values in the dataset.

The *arithmetic mean* can be calculated using Equation (1).

$$AM = arithmetic\ mean = \frac{1}{n}\sum_{i=1}^{n} x_i, \tag{1}$$

where x_i is the data point value, and n is the total number of data points in the set. The arithmetic mean is used for data sets with no significant outliers (values that are much larger or smaller than most) [66].

Example 1. *If we consider a set of fuzzy numbers X, the arithmetic mean is calculated in Equations (2)–(5).*

$$X_1 = \{3, 4, 5\},\ X_2 = \{4, 5, 6\},\ X_3 = \{4, 5, 6\},\ X_4 = \{3, 4, 5\} \tag{2}$$

$$AM^l = \frac{3+4+4+3}{4} = 3.5 \tag{3}$$

$$AM^m = \frac{4+5+5+4}{4} = 4.5 \tag{4}$$

$$AM^u = \frac{5+6+6+5}{4} = 5.5 \tag{5}$$

2.2.2. Geometric Mean

The geometric mean finds the nth root of the product of a set of n positive values. Thus, the geometric mean is represented as the multiplicative mean. It entails finding the product of the number and then raising that value by the reciprocal number of data points contributing to the product [67].

The geometric mean can be calculated using Equation (2).

$$GM = geometric\ mean = \sqrt[n]{\left(\prod_{i=1}^{n} x_{ij}\right)}, \tag{6}$$

where x_i is the data point value, and n is the total number of data points in the set. The geometric mean has an advantage over the arithmetical mean because it is less affected by outliers (the geometric mean normalizes the dataset, and the values are averaged out). The geometric mean is not influenced by skewed distribution as the arithmetic mean is. In addition, the geometric mean is better for intermediate values between two others. Thus, the geometric mean could be applied in the fuzzy methodology as the fuzzy geometric mean of given values in datasets [66,67].

Example 2. *If we consider a set of fuzzy numbers X, the geometric mean is calculated in Equations (7)–(10).*

$$X_1 = \{3, 4, 5\},\ X_2 = \{4, 5, 6\},\ X_3 = \{4, 5, 6\},\ X_4 = \{3, 4, 5\} \tag{7}$$

$$GM^l = \sqrt[4]{(3*4*4*3)} = 3.46 \tag{8}$$

$$GM^m = \sqrt[4]{(4*5*5*4)} = 4.47 \tag{9}$$

$$GM^u = \sqrt[4]{(5*6*6*5)} = 5.48 \tag{10}$$

2.2.3. Dombi Bonferroni Mean

The Dombi Bonferroni mean is based on the fuzzy triangular numbers (TrFNs) operators, and the TrFN Dombi–Bonferroni mean (TrFNDMB) operator is proposed [68].

Theorem 1. *Let $\widetilde{\varphi}_j = \left(\varphi_j^l, \varphi_j^m, \varphi_j^u\right)$, $(j = 1, 2, \ldots, n)$, be a collection of TrFNs, then the TrFNDBM operator is defined by Equation (11).*

$$TrFNDBM^{p,q,\rho}(\widetilde{\varphi}_1,\widetilde{\varphi}_2,\ldots,\widetilde{\varphi}_n)=\left(\frac{1}{n(n-1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\widetilde{\varphi}_i^{p}\widetilde{\varphi}_j^{q}\right)^{\frac{1}{p+q}}$$

$$=\left(\begin{array}{l} =\dfrac{\sum_{i=1}^{n}\varphi_i^l}{1+\left\{\frac{1}{p+q}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\dfrac{n(n-1)}{\dfrac{1}{\left(p\left(\frac{1-f\left(\varphi_i^l\right)}{f\left(\varphi_i^l\right)}\right)^{\rho}+q\left(\frac{1-f\left(\varphi_j^l\right)}{f\left(\varphi_j^l\right)}\right)^{\rho}\right)}}\right\}^{1/\rho}} \\ =\dfrac{\sum_{i=1}^{n}\varphi_i^m}{1+\left\{\frac{1}{p+q}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\dfrac{n(n-1)}{\dfrac{1}{\left(p\left(\frac{1-f\left(\varphi_i^m\right)}{f\left(\varphi_i^m\right)}\right)^{\rho}+q\left(\frac{1-f\left(\varphi_j^m\right)}{f\left(\varphi_j^m\right)}\right)^{\rho}\right)}}\right\}^{1/\rho}}, \\ =\dfrac{\sum_{i=1}^{n}\varphi_i^u}{1+\left\{\frac{1}{p+q}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\dfrac{n(n-1)}{\dfrac{1}{\left(p\left(\frac{1-f\left(\varphi_i^u\right)}{f\left(\varphi_i^u\right)}\right)^{\rho}+q\left(\frac{1-f\left(\varphi_j^u\right)}{f\left(\varphi_j^u\right)}\right)^{\rho}\right)}}\right\}^{1/\rho}} \end{array}\right), \tag{11}$$

where $f(\widetilde{\varphi}_i)=\left(f\left(\varphi_i^l\right),f\left(\varphi_i^m\right),f\left(\varphi_i^u\right)\right)=\left(\frac{\varphi_i^l}{\sum_{i=1}^{n}\varphi_i^l},\frac{\varphi_i^m}{\sum_{i=1}^{n}\varphi_i^m},\frac{\varphi_i^u}{\sum_{i=1}^{n}\varphi_i^u}\right)$ *represents the fuzzy function.*

Theorem 2 (Idempotency). *Set* $\widetilde{\varphi}_j=\left(\varphi_j^l,\varphi_j^m,\varphi_j^u\right)$; $(j=1,2,\ldots,n)$, *collection of TrFNs in R, if* $\widetilde{\varphi}_i=\widetilde{\varphi}$, *then* $TrFNDBM^{p,q,\rho}(\widetilde{\varphi}_1,\widetilde{\varphi}_2,\ldots,\widetilde{\varphi}_n)=TrFNDBM^{p,q,\rho}(\widetilde{\varphi},\widetilde{\varphi},\ldots,\widetilde{\varphi})$.

Theorem 3 (Boundedness). *Set* $\widetilde{\varphi}_j=\left(\varphi_j^l,\varphi_j^m,\varphi_j^u\right)$;$(j=1,2,\ldots,n)$, *collection of TrFNs in R, let* $\widetilde{\varphi}^-=\left(min\varphi_i^l,min\varphi_i^m,min\varphi_i^u\right)$ *and* $\widetilde{\varphi}^+=\left(max\varphi_i^l,max\varphi_i^m,max\varphi_i^u\right)$ *then* $\widetilde{\varphi}^-\leq TrFNDBM^{p,q,\rho}(\widetilde{\varphi}_1,\widetilde{\varphi}_2,\ldots,\widetilde{\varphi}_n)\leq\widetilde{\varphi}^+$.

Theorem 4 (Commutativity). *Let the gray set* $\left(\widetilde{\varphi}_1',\widetilde{\varphi}_2',\ldots,\widetilde{\varphi}_n'\right)$ *be any permutation of* $(\widetilde{\varphi}_1,\widetilde{\varphi}_2,\ldots,\widetilde{\varphi}_n)$. *Then* $TrFNDBM^{p,q,\rho}(\widetilde{\varphi}_1,\widetilde{\varphi}_2,\ldots,\widetilde{\varphi}_n)=TrFNDBM^{p,q,\rho}\left(\widetilde{\varphi}_1',\widetilde{\varphi}_2',\ldots,\widetilde{\varphi}_n'\right)$.

More detailed analysis could be found in [41,68].

Example 3. *If we consider a set of fuzzy numbers* $\widetilde{\varphi}_i$ *as* $\widetilde{\varphi}_1=(3,4,5)$, $\widetilde{\varphi}_2=(4,5,6)$, $\widetilde{\varphi}_3=(4,5,6)$ *and* $\widetilde{\varphi}_4=(3,4,5)$ *and* $p=q=\rho=1$, *the Dombi Bonferroni mean is calculated by Equation (12).*

$$f(\varphi_1^l) = 3/14 = 0.214;\ f(\varphi_2^l) = 4/14 = 0.286;\ f(\varphi_3^l) = 4/14 = 0.286\ \ldots;$$
$$f(\varphi_4^m) = 4/18 = 0.222;\ \ldots;\ \varphi_3^u = 6/22 = 0.273;\ \varphi_4^u = 5/22 = 0.227$$
$$\frac{1-f\left(\varphi_1^l\right)}{f\left(\varphi_1^l\right)} = 3.67;\ \frac{1-f\left(\varphi_2^l\right)}{f\left(\varphi_2^l\right)} = 2.49;\ \ldots;\frac{1-f(\varphi_1^m)}{f(\varphi_1^m)} = 3.5;\ \ldots;\frac{1-f(\varphi_4^u)}{f(\varphi_4^u)} = 3.4$$
$$\mathrm{TrFNDBM}^{1,1,1}\{(3,4,5)(4,5,6)(4,5,6)(3,4,5)\} =$$
$$= \frac{3+4+4+3}{1+\left\{\frac{1}{1+1}\frac{4(4-1)}{\left(\frac{1}{3{,}67}+\frac{1}{2.49}\right)^1+\left(\frac{1}{3{,}67}+\frac{1}{2.49}\right)^1+\left(\frac{1}{3{,}67}+\frac{1}{3{,}67}\right)^1+\left(\frac{1}{2.49}+\frac{1}{3{,}67}\right)^1+\left(\frac{1}{2.49}+\frac{1}{2.49}\right)^1+\left(\frac{1}{2.49}+\frac{1}{3{,}67}\right)^1+\ldots+\left(\frac{1}{3{,}67}+\frac{1}{3{,}67}\right)^1+\left(\frac{1}{3{,}67}+\frac{1}{2.49}\right)^1+\left(\frac{1}{3{,}67}+\frac{1}{2.49}\right)^1}\right\}^{\frac{1}{1}}}, \tag{12}$$
$$= \frac{4+5+5+4}{1+\left\{\frac{1}{1+1}\frac{4(4-1)}{\left(\frac{1}{3{,}5}+\frac{1}{2.59}\right)^1+\left(\frac{1}{3{,}5}+\frac{1}{2.59}\right)^1+\left(\frac{1}{3{,}5}+\frac{1}{3{,}5}\right)^1+\left(\frac{1}{2.59}+\frac{1}{3{,}5}\right)^1+\left(\frac{1}{2.59}+\frac{1}{2.59}\right)^1+\left(\frac{1}{2.59}+\frac{1}{3{,}5}\right)^1+\ldots+\left(\frac{1}{3{,}5}+\frac{1}{3{,}5}\right)^1+\left(\frac{1}{3{,}5}+\frac{1}{2.59}\right)^1+\left(\frac{1}{3{,}5}+\frac{1}{2.59}\right)^1}\right\}^{1/1}},$$
$$= \frac{5+6+6+5}{1+\left\{\frac{1}{1+1}\frac{4(4-1)}{\left(\frac{1}{3{,}4}+\frac{1}{2.66}\right)^1+\left(\frac{1}{3{,}4}+\frac{1}{2.66}\right)^1+\left(\frac{1}{3{,}4}+\frac{1}{3{,}4}\right)^1+\left(\frac{1}{2.66}+\frac{1}{3{,}4}\right)^1+\left(\frac{1}{2.66}+\frac{1}{2.66}\right)^1+\left(\frac{1}{2.66}+\frac{1}{3{,}4}\right)^1+\ldots+\left(\frac{1}{3{,}4}+\frac{1}{3{,}4}\right)^1+\left(\frac{1}{3{,}4}+\frac{1}{2.66}\right)^1+\left(\frac{1}{3{,}4}+\frac{1}{2.66}\right)^1}\right\}^{1/1}},$$
$$= (8.036,\ 10.32,\ 12.6)$$

3. Case Study—Selection of Waste Oil Transfer Station Location

Waste oil, unlike other types of waste, in addition to its physical and chemical properties, also has dangerous properties, and accordingly, the negative consequences in case of inadequate disposal can have a larger scale and a greater degree of impact on the entire environment. Precisely because of the characteristics of waste oils, in order to reduce the probability of an accident and the magnitude of the consequences, it is necessary to manage the entire cycle through which lubricating oils pass, from their creation until the end of their use, when they become waste oils. Although today's legislation is adapted to the regulations of the European Union (Directive 75/439/EEC on the disposal of waste oils) [69], a problem should be singled out: the lack of a suitable network of waste oil management facilities, that is, the absence of facilities for the collection and some of the types of waste oil treatment.

The process of choosing the optimal location for a waste oil transfer station is a very complex process and requires the consideration of numerous factors that may have a negative impact. In this study, the criteria set consists of 8 criteria. Those criteria are based on the factors that most affect the problem of location selection in the field of waste management. The criteria set is chosen based on the authors' previous experience—a literature review for the specific type of problem (location selection), regulations for transfer stations and landfills, long-term academic practice in the field of waste management (scientific and practical expertise), and consultations with representatives of local government authorities. In addition, three possible locations, i.e., three alternative solutions, are taken into account.

Criterion C_1: Distance from the traffic infrastructure [km]—The transport of hazardous materials like waste oil should be directed to transit roads whenever possible. This will result in dangerous waste being transported through sparsely populated areas. The direct consequence, if the transport is carried out on transit roads, is the reduction of the risk of accident situations. In addition, there is a reduction of harmful effects on the population and the environment in the case of an accident.

Criterion C_2: Construction costs [EUR]—Construction costs are specific and differ for each location. The final project costs and compensation costs for a particular landfill or transfer station depend on the site's terrain, soil type, climate factors, site-specific restrictions, and regulatory factors. The type of waste defines the scope of the construction needed to adapt the site to its intended purpose regarding environment protection, potential groundwater contamination, and public health. Total costs or life cycle costs are defined as costs incurred from the moment the landfill is conceived and cover the period up to thirty years after closure.

Criterion C_3: Possible impact on the environment in the case of accidents [%]—Assessment of this criterion is primarily based on determining whether the location of the transfer station is located near vulnerable environmental areas, protected cultural assets, parks, etc. This way, the magnitude of the consequences caused by the accidents could be predicted. Certainly, the greatest risk would be if the transfer station is in the immediate vicinity of sensitive areas of the environment, while the lowest risk would be if the zone of influence of potential dangers is not nearby and does not touch these sensitive surfaces.

Criterion C_4: Distance from the protected areas, natural assets, and facilities [km]—The impact of an accident during the transport of dangerous wastes could have incomprehensible proportions on the surfaces belonging to the so-called "ecological zones". To determine the location and size of these areas, as well as the location of protected buildings, it is necessary to look at special types of maps when deciding on choosing a location to construct a waste oil transfer station. Special maps that show areas that endangered and protected species of flora and fauna inhabit can be of immense importance. Still, the creation of such maps is the responsibility of the state and city authorities, and it is they who should enable the availability of such maps. Consequently, a site that is not located near the mentioned areas could be selected, and therefore the transfer station would not pose a danger to endangered species.

Criterion C_5: Topography and soil characteristics [%]—When choosing a location for a transfer station, it is essential to consider the geological and topographical characteristics of the land. It is recommended to avoid karst terrains and areas, as well as rocky areas. The site should be geologically stable and have a minimal potential impact on groundwater. The topography when choosing the location of the transfer station can be significant due to the influence of the wind. Also, the topography should be adequately considered towards the construction of the transfer station itself because inappropriate topography can significantly increase construction costs.

Criterion C_6: Distance and impact on the aquatic ecosystems [km]—Landfills and transfer stations are generally not allowed in areas where there are large and sensitive water basins or in protected sea, lake, and river areas. Suppose it is necessary to build a landfill in one of those areas. In that case, it will require significant resources to reduce the potential impact on water courses to protect their flora and fauna. The minimum distance of landfills and transfer stations from water courses is about 500 m, and they are also recommended to be built in locations that have not been flooded in the previous 100 years. The stated distances can be even greater if it is estimated that uncontrolled accidents can cause great damage to the aquatic ecosystem in a certain area.

Criterion C_7: Distance from the waste generators [km]—It can be defined and presented as the total distance from the waste generators to the transfer station. In the literature, it is generally expressed in kilometers. Practically the distance should be as short as possible, but for safety reasons, that might not be the most optimal solution. In the case of the shortest possible distance between the waste generator and the transfer station, the waste oil transport via road will take a shorter time, and potential danger to other road users and the environment will also be reduced. But if the shortest transport route implies that the transport vehicle goes through inhabited or protected areas, it should certainly not be considered a priority.

Criterion C_8: Population density (number of inhabitants per km^2)—the number of inhabitants exposed to hazardous waste, i.e., waste oil, is a key factor in the literature to determine the consequences in case of an accident. The number of inhabitants who are potentially exposed to the effects of hazardous waste can be determined based on the population density of certain categories of the population (residents, employees, motorized residents) or by a combination of these three variables. Population density (per km^2), which is used as one of the parameters for defining the size of the consequences, is obtained as a ratio of the total number of inhabitants located within the influence zone and the area of the influence zone.

The first location (Alternative 1) chosen for a potential transfer station is on the Čamurlija road. The second location (Alternative 2) is on the road leading to Niška Banja, while the third potential location (Alternative 3) is the land near the Niš Penitentiary, i.e., on the road to the 9 May settlement. The position of all three locations is shown in Figure 2, and for each location, a comparison was made in relation to the eight criteria that were selected and evaluated by experts in the previous part of the work.

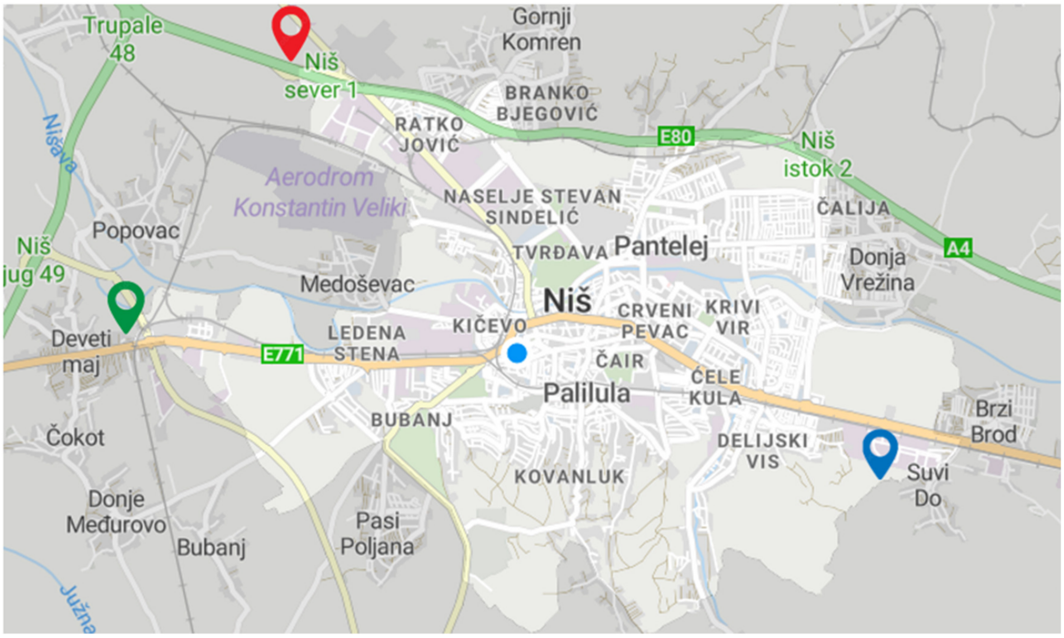

Figure 2. Proposed locations (alternative solutions) for the transfer station.

Alternative 1 is represented with a red symbol. Alternative 2 is represented with a blue symbol. Alternative 3 is represented with a green symbol.

When it comes to the criterion of the distance from the traffic infrastructure, the most favorable location is Alternative 1, which is approximately 5.5 km away from the highway and the nearest railway station. Alternative 3 is 6 km away, so it is the second most favorable location, while Alternative 2 is 6.5 km away, which is why it is the least favorable location according to this criterion.

To see the most favorable alternative in relation to the criterion of construction costs, the average land prices in the vicinity of the locations were considered. Based on that, the most favorable alternative is the location near the Niš Penitentiary, i.e., Alternative 3, where land prices are lower compared to the other two locations. Another location that stands out as favorable in relation to the criterion of construction costs is Alternative 1. Given that the land prices are the most expensive in the vicinity of Alternative 2, it is the least favorable compared to the other two locations.

Based on the previously reviewed results in relation to other criteria, the location's favorability was assessed in relation to the criterion of the possible impact on the environment in the case of accidents. If an accident were to occur, the greatest consequences for the environment would be if the waste oil transfer station is located at Alternative 3, followed by Alternative 1, and the most favorable location in relation to this criterion is Alternative 2.

To choose the most favorable alternative in relation to the distance from the protected areas, natural assets, and facilities, the total distance of locations in relation to characteristics of protected areas and cultural monuments was considered, such as Jelašnica gorge, the archaeological site of Mediana, the Skull Tower, the Memorial park Bubanj, the Fortress of Niš, and the Red Cross concentration camp. The longest total distance from the mentioned protected areas and cultural monuments is from Alternative 1, making it the most favorable regarding the mentioned criterion. The second favorable location, which has a slightly shorter distance compared to Alternative 1, is Alternative 2. Alternative 3 is the least favorable location in relation to the distance of protected areas, natural assets, and facilities because the total distance is the shortest.

In relation to the criterion of topography and soil characteristics, all three alternatives are approximately equally favorable. However, the most favorable location for the construction of a transfer station with somewhat better characteristics is Alternative 2. The second favorable location is Alternative 3, while in relation to the mentioned criterion, the least favorable location is the land next to the Čamurlija road, more precisely, Alternative 1.

To determine the most favorable location in relation to the criterion of distance and impact on the aquatic ecosystems, the distance of the locations in relation to the flows of the two largest rivers in this area, the Nišava and the South Morava rivers, was considered. Bearing in mind that Alternative 3 is the furthest from the courses of these two rivers, it is considered the most favorable. Alternative 1 is slightly closer to the two rivers and is considered the second favorable location. The location on the road to Niška Banja, i.e., Alternative 2, is the least favorable in relation to the mentioned criterion. Although the stream of the South Morava River is located at a greater distance from Alternative 2, the stream of the Nišava River is only 0.5 km from the location, so in the event of an accident, there could be a major impact on the water ecosystem.

When it comes to the criterion of the distance from the waste generators, the distance of all car service centers and technical workshops where the research was conducted was calculated in relation to each location. The total distance of Alternative 2 is the shorters in relation to all respondents, so it is also the most favorable location. When the distance of all respondents is calculated in relation to Alternative 1 and Alternative 3, it can be concluded that the difference is not very big. However, the location on the Čamurlija road is somewhat closer when the distance of the respondents is added, in relation to Alternative 3, and that is why it is the second most favorable location. Consequently, Alternative 3 is the least favorable.

The average population density of the municipality where the alternatives are located was considered to select the most favorable location in relation to the population density criterion. According to official data, the municipality of Niška Banja has the lowest population density, so Alternative 2 is, therefore, the most favorable in relation to this criterion. Alternative 1, located on the territory of the Red Cross municipality, is another favorable location. Since the municipality of Palilula is the most populated compared to the other two municipalities, it makes Alternative 3 the least favorable.

The fuzzy decision matrix based on the previously described alternatives (locations) and the defined criteria set is formed and presented in Table 2.

Table 2. Location's performance ratings—fuzzy decision matrix.

	C_1 [km]			**C_2 [EUR]**			**C_3 [%]**			**C_4 [km]**		
	min			**min**			**min**			**max**		
A_1	5.5	5.5	5.5	16,800	17,000	17,580	81.4	83.6	85	65.8	65.8	65.8
A_2	6.5	6.5	6.5	19,000	19,500	19,800	74.3	75.8	76.2	52.4	52.4	52.4
A_3	6	6	6	10,700	11,000	11,400	91.3	92.4	94.5	48.5	48.5	48.5
	C_5 [%]			**C_6 [km]**			**C_7 [km]**			**C_8 [Number of Inhabitants per km^2]**		
	max			**max**			**min**			**min**		
A_1	81	82.1	82.8	4	4	4	170.1	170.1	170.1	178	178	178
A_2	86.3	87.6	88	0.5	0.5	0.5	91.55	91.55	91.55	101	101	101
A_3	83.2	84.3	85.1	4.9	4.9	4.9	173.2	173.2	173.2	631	631	631

The team of experts also evaluated the significance of the defined criteria according to the requirements of each of the considered criteria weights methods: F-AHP (Table 3), F-PIPRECIA (Table 4), and F-FUCOM (Table 5). These comparison matrixes are essential for criteria weight determination, and therefore they were created and presented individually in the following tables. Each of the methods has a defined scale based on which criteria are compared.

Table 3. Comparison of criteria by three experts based on fuzzy AHP methods.

		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	E_1	(1,1,1)	(1,3/2,2)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(1,3/2,2)	(2/7,1/3,2/5)	(1/3,2/5,1/2)	(2/5,1/2,2/3)
	E_2	(1,1,1)	(3/2,2,5/2)	(2/7,1/3,2/5)	(1/3,2/5,1/2)	(1/2,1,3/2)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(1/3,2/5,1/2)
	E_3	(1,1,1)	(1,3/2,2)	(2/7,1/3,2/5)	(1/3,2/5,1/2)	(1/2,1,3/2)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(1/2,2/3,1)
C_2	E_1	(1/2,2/3,1)	(1,1,1)	(1/3,2/5,1/2)	(1/2,2/3,1)	(1,3/2,2)	(1/3,2/5,1/2)	(1/2,2/3,1)	(2/5,1/2,2/3)
	E_2	(2/5,1/2,2/3)	(1,1,1)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(2/3,1,2)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(1/3,2/5,1/2)
	E_3	(1/2,2/3,1)	(1,1,1)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(1,3/2,2)	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)
C_3	E_1	(5/2,3,7/2)	(2,5/2,3)	(1,1,1)	(3/2,2,5/2)	(5/2,3,7/2)	(1,3/2,2)	(3/2,2,5/2)	(3/2,2,5/2)
	E_2	(5/2,3,7/2)	(5/2,3,7/2)	(1,1,1)	(1/2,1,3/2)	(5/2,3,7/2)	(1/2,1,3/2)	(2,5/2,3)	(2/3,1,2)
	E_3	(5/2,3,7/2)	(5/2,3,7/2)	(1,1,1)	(1/2,1,3/2)	(5/2,3,7/2)	(1/2,1,3/2)	(3/2,2,5/2)	(3/2,2,5/2)
C_4	E_1	(3/2,2,5/2)	(1,3/2,2)	(2/5,1/2,2/3)	(1,1,1)	(1,3/2,2)	(1,1,1)	(1,3/2,2)	(3/2,2,5/2)
	E_2	(2,5/2,3)	(3/2,2,5/2)	(2/3,1,2)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(2,5/2,3)	(1,1,1)
	E_3	(2,5/2,3)	(3/2,2,5/2)	(2/3,1,2)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)
C_5	E_1	(1/2,2/3,1)	(1/2,2/3,1)	(2/7,1/3,2/5)	(1/2,2/3,1)	(1,1,1)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)
	E_2	(2/3,1,2)	(1/2,1,3/2)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(1,1,1)	(2/7,1/3,2/5)	(1/3,2/5,1/2)	(1/2,2/3,1)
	E_3	(2/3,1,2)	(1/2,2/3,1)	(2/7,1/3,5/2)	(2/5,1/2,2/3)	(1,1,1)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2/3,1,2)
C_6	E_1	(5/2,3,7/2)	(2,5/2,3)	(1/2,2/3,1)	(1,1,1)	(2,5/2,3)	(1,1,1)	(1,3/2,2)	(3/2,2,5/2)
	E_2	(5/2,3,7/2)	(5/2,3,7/2)	(2/3,1,2)	(1,1,1)	(5/2,3,7/2)	(1,1,1)	(3/2,2,5/2)	(1/2,1,3/2)
	E_3	(5/2,3,7/2)	(2,5/2,3)	(2/3,1,2)	(1,1,1)	(2,5/2,3)	(1,1,1)	(1/2,1,3/2)	(3/2,2,5/2)
C_7	E_1	(2,5/2,3)	(1,3/2,2)	(2/5,1/2,2/3)	(1/2,2/3,1)	(2,5/2,3)	(1/2,2/3,1)	(1,1,1)	(3/2,2,5/2)
	E_2	(5/2,3,7/2)	(3/2,2,5/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2,5/2,3)	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,2)
	E_3	(1,3/2,2)	(1,3/2,2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2,5/2,3)	(2/3,1,2)	(1,1,1)	(1,3/2,2)
C_8	E_1	(3/2,2,5/2)	(3/2,2,5/2	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)
	E_2	(2,5/2,3)	(2,5/2,3)	(1/2,1,3/2)	(1,1,1)	(1,3/2,2)	(2/3,1,2)	(1/2,1,3/2)	(1,1,1)
	E_3	(1,3/2,2)	(1,3/2,2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1/2,1,3/2)	(2/5,1/2,2/3)	(1/2,2/3,1)	(1,1,1)

Table 4. Comparison of criteria by three experts based on fuzzy PIPRECIA methods.

		PIPRECIA-D			PIPRECIA-I
C_1	E_1		C_8	E_1	
	E_2			E_2	
	E_3			E_3	
C_2	E_1	(0.286,0.333,0.400)	C_7	E_1	(0.250,0.286,0.333)
	E_2	(0.250,0.286,0.333)		E_2	(0.286,0.333,0.400)
	E_3	(0.333,0.400,0.500)		E_3	(0.286,0.333,0.400)
C_3	E_1	(1.400,1.600,1.650)	C_6	E_1	(1.200,1.300,1.350)
	E_2	(1.300,1.450,1.500)		E_2	(1.200,1.300,1.350)
	E_3	(1.500,1.750,1.800)		E_3	(1.300,1.450,1.500)
C_4	E_1	(0.500,0.667,1.000)	C_5	E_1	(0.250,0.250,0.333)
	E_2	(0.400,0.500,0.667)		E_2	(0.222,0.333,0.286)
	E_3	(0.500,0.667,1.000)		E_3	(0.250,0.286,0.333)
C_5	E_1	(0.400,0.500,0.667)	C_4	E_1	(1.100,1.150,1.200)
	E_2	(0.333,0.400,0.500)		E_2	(1.100,1.150,1.200)
	E_3	(0.400,0.500,0.667)		E_3	(1.200,1.300,1.350)
C_6	E_1	(1.000,1.000,1.050)	C_3	E_1	(1.200,1.300,1.350)
	E_2	(1.200,1.300,1.350)		E_2	(1.200,1.300,1.350)
	E_3	(1.100,1.150,1.200)		E_3	(1.100,1.150,1.200)

Table 4. *Cont.*

		PIPRECIA-D			PIPRECIA-I
C_7	E_1	(0.250,0.286,0.333)	C_2	E_1	(0.222,0.250,0.286)
	E_2	(0.333,0.400,0.500)		E_2	(0.250,0.286,0.333)
	E_3	(0.286,0.333,0.400)		E_3	(0.222,0.250,0.286)
C_8	E_1	(1.100,1.150,1.200)	C_1	E_1	(1.000,1.000,1.050)
	E_2	(1.100,1.150,1.200)		E_2	(1.000,1.000,1.050)
	E_3	(1.000,1.000,1.050)		E_3	(1.100,1.150,1.200)

Table 5. Comparison of criteria by three experts based on fuzzy FUCOM methods.

	E_1		E_2		E_3
C_6	(1,1,1)	C_3	(1,1,1)	C_3	(1,1,1)
C_3	(2/3,1,3/2)	C_6	(2/3,1,3/2)	C_6	(2/3,1,3/2)
C_7	(3/2,2,5/2)	C_4	(2/3,1,3/2)	C_4	(2/3,1,3/2)
C_4	(3/2,2,5/2)	C_7	(3/2,2,5/2)	C_1	(3/2,2,5/2)
C_1	(3/2,2,5/2)	C_1	(3/2,2,5/2)	C_8	(3/2,2,5/2)
C_8	(5/2,3,7/2)	C_8	(5/2,3,7/2)	C_7	(5/2,3,7/2)
C_5	(7/2,4,9/2)	C_2	(5/2,3,7/2)	C_5	(7/2,4,9/2)
C_2	(7/2,4,9/2)	C_5	(7/2,4,9/2)	C_2	(7/2,4,9/2)

Table 3 shows the criteria comparison matrix based on the fuzzy AHP method, which was formed based on the scale that can be found in paper [56].

Table 4 shows the criteria comparison matrix based on the fuzzy PIPRECIA method, which was formed based on the scale that can be found in paper [70].

Table 5 shows the criteria comparison matrix based on the fuzzy FUCOM method, which was formed based on the scale that can be found in paper [63].

4. Results and Discussion

When the pairwise comparison of each criterion is made, the criteria weights can be determined. The criteria weights calculation is unique for each applied fuzzy MCDM method, and more details are given in Section 2.1. Multi-Criteria Decision-Making (MCDM) of this paper. The aggregation of the calculated criteria weights were obtained by applying each proposed aggregation operator.

The aggregated criteria weights for each combination of the fuzzy MCDM method and aggregation operator applied are presented in the following tables.

The criteria weights obtained by F-AHP, F-PIPRECIA, and F-FUCOM in relation to the F-AM aggregation operator are presented in Tables 6–8.

Table 6. Aggregated criteria weights obtained by F-AHP and F-AM.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
l	0	0	0.288	0.203	0	0.250	0.166	0.093
m	0	0	0.288	0.203	0	0.250	0.166	0.093
u	0	0	0.288	0.203	0	0.250	0.166	0.093

Table 7. Aggregated criteria weights obtained by F-PIPRECIA and F-AM.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
l	0.077	0.555	0.092	0.068	0.051	0.078	0.056	0.088
m	0.121	0.089	0.189	0.139	0.100	0.143	0.090	0.130
u	0.196	0.145	0.350	0.300	0.220	0.302	0.186	0.245

Table 8. Aggregated criteria weights obtained by F-FUCOM and F-AM.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
l	0.087	0.090	0.169	0.134	0.077	0.180	0.078	0.051
m	0.122	0.114	0.202	0.165	0.095	0.218	0.099	0.079
u	0.042	0.038	0.068	0.052	0.031	0.073	0.034	0.035

In the comparison of the aggregation operator F-AM in relation to each fuzzy method (F-AHP, F-PIPRECIA, F-FUCOM), as presented in Tables 6–8, the aggregation operator F-AM clearly stands out in combination with F-AHP where it gives quite unclear results. The weights of certain criteria have zero value. In combination with other fuzzy methods, there are deviations, but not to an excessive extent. The weight coefficients are very close in the values for certain criteria, while deviations mainly occur for criteria C2, C4, C6, and C8.

The criteria weights obtained by the F-AHP, F-PIPRECIA, and F-FUCOM MCDM methods in relation to the F-GM aggregation operator are presented in Tables 9–11.

Table 9. Aggregated criteria weights obtained by F-AHP and F-GM.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
l	0	0	0.280	0.201	0	0.245	0.169	0.105
m	0	0	0.280	0.201	0	0.245	0.169	0.105
u	0	0	0.280	0.201	0	0.245	0.169	0.105

Table 10. Aggregated criteria weights obtained by F-PIPRECIA and F-GM.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
l	0.075	0.054	0.091	0.068	0.051	0.077	0.055	0.087
m	0.120	0.088	0.189	0.139	0.099	0.143	0.090	0.129
u	0.196	0.145	0.342	0.283	0.208	0.291	0.181	0.242

Table 11. Aggregated criteria weights obtained by F-FUCOM and F-GM.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
l	0.039	0.059	0.107	0.061	0.047	0.104	0.039	0.040
m	0.118	0.104	0.205	0.155	0.089	0.219	0.101	0.097
u	0.127	0.115	0.205	0.156	0.093	0.219	0.101	0.104

The results were also unclear for the aggregation operator F-GM in combination with fuzzy methods, as in the previous case when the aggregation operator F-AM was applied with the F-AHP method. In combination with the F-PIPRECIA method, the result is the clearest. The F-FUCOM method showed that some criteria weigh the same or very close to real and maximal values.

The criteria weights obtained by F-AHP, F-PIPRECIA, and F-FUCOM in relation to the DBM aggregation operator are presented in Tables 12–14.

Table 12. Aggregated criteria weights obtained by F-AHP and F-DBM.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
l	0	0	0.574	0.399	0	0.493	0.340	0.207
m	0	0	0.574	0.399	0	0.493	0.340	0.207
u	0	0	0.574	0.399	0	0.493	0.340	0.207

Table 13. Aggregated criteria weights obtained by F-PIPRECIA and F-DBM.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
l	0.157	0.111	0.186	0.136	0.102	0.156	0.113	0.177
m	0.242	0.178	0.379	0.279	0.200	0.286	0.180	0.260
u	0.391	0.291	0.710	0.616	0.452	0.618	0.378	0.493

Table 14. Aggregated criteria weights obtained by F-FUCOM and F-DBM.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
l	0.082	0.117	0.215	0.128	0.095	0.209	0.080	0.081
m	0.239	0.208	0.411	0.314	0.179	0.438	0.204	0.196
u	0.257	0.231	0.411	0.316	0.187	0.438	0.204	0.216

In the final case, i.e., in the combination of the aggregation operator F-DBM with fuzzy methods, it can be seen that the F-AHP method is not as reliable as in the previous cases. However, when F-DBM is combined with the F-PIPRECIA method, as with the other aggregation operators, the clearer results of the weighting coefficients of the criteria are calculated. The F-FUCOM has the same or very close values in the case of actual and maximal values, similar to the other aggregation operators.

Based on the observed results, it is noticeable that the most reliable combination of all fuzzy aggregation operators is with the F-PIPRECIA method, where the clearest results are obtained. In the research conducted by Krejči and Stoklasa [66], it is stated that AM, especially in combination with the F-AHP method, does not give clear results, which in the present case proved to be true.

The obtained results of each fuzzy aggregation operator in relation to each fuzzy MCDM method were used for further calculation, i.e., for the ranking of alternatives. The weight coefficients of each aggregation operator are combined with the F-WASPAS method, as can be seen in Table 15.

Table 15. The location selection of the transfer station using the integrated F-WASPAS method.

	F-AHP + F-WASPAS					
	AM	**Rank**	**GM**	**Rank**	**DB**	**Rank**
A_1	0.796073	1	0.791070	1	0.837682	1
A_2	0.627428	3	0.632906	3	0.562654	3
A_3	0.699015	2	0.687043	2	0.663013	2
	F-PIPRECIA + F-WASPAS					
	AM	**Rank**	**GM**	**Rank**	**DB**	**Rank**
A_1	0.84728	1	0.84161	1	0.86850	1
A_2	0.74134	3	0.73871	2	0.69386	3
A_3	0.74244	2	0.73821	3	0.70086	2
	F-FUCOM + F-WASPAS					
	AM	**Rank**	**GM**	**Rank**	**DB**	**Rank**
A_1	0.733256	1	0.778237	1	0.896734	1
A_2	0.599188	3	0.630359	3	0.635844	3
A_3	0.703036	2	0.734144	2	0.808014	2

Based on each aggregation operator and the comparison of the F-AHP + F-WASPAS, F-PIPRECIA + F-WASPAS, and F-FUCOM + F-WASPAS methods, one can see and conclude that the first alternative, i.e., the location on the Čamurlija road, is the best alternative solution, while in the case of the second and third-ranked alternatives, a deviation is present. In most cases, Alternative 3, i.e., the land near the Niš Penitentiary, is in second place. At the same time, the last place is mostly occupied by Alternative 2, i.e., the land on the road leading to Niška Banja. As seen in the fuzzy aggregation operator AM and GM case, Alternative 2 and Alternative 3 had very close values.

Based on results from Table 14 and the complete ranking of each comparative method, one can observe that there is no significant deviation in the rankings. The deviation occurred in the case of the comparison of the F-PIPRECIA + F-WASPAS method with the F-GM aggregation operator application, where the first or best-ranked alternative is in the first place, while the second and third alternatives changed places in relation to the other rankings, but with an exceedingly small deviation when compared. It can be concluded that the weight coefficients of each aggregation approach did not significantly affect the complete ranking of the alternatives.

5. Conclusions

The location selection problem can be extraordinarily complex and complicated, especially when environmental, hazardous, and public health factors are involved. Waste oil is one of the most dangerous hazardous wastes that must be treated under the defined laws and regulations to protect the environment and public health. Transfer stations are vital links in establishing the waste oil treatment system.

This research demonstrated the applicability and presented a comparison of three fuzzy aggregation operators (AM, GM, and DB) coupled with three fuzzy criteria weight methods (F-AHP, F-PIPRECIA, and F-FUCOM) and a single ranking MCDM method (F-WASPAS). A real case study, dealing with the problem of location selection for the used motor oil transfer station in the city of Niš, was used. The best location for the construction of the waste oil transfer station is Alternative 1 (the land on the Čamurlija road), while Alternative 3 (the land near the Niš Penitentiary) and Alternative 2 (the land on the road to Niška Banja) are the second and third best locations, respectively.

The results obtained in the study showed that the initial hypothesis was correct, i.e., that the application of three different fuzzy aggregation operators, for solving the same decision-making problem, according to opinions and attitudes of the same experts, gives different values of criteria weights. That means that the selection of the aggregation operator has a significant impact on the values of criteria weight coefficients, and without a deeper analysis of this impact the final ranking of alternatives may be determined incorrectly.

On the other hand, in this real case study, the attributes of the alternatives, according to different criteria, are such that the values of the weighting coefficients do not have a dominant influence on the final ranking. That is the main reason why the alternatives showed rank order stability without deviations.

In addition, the authors expect that these results will stimulate future research on the impact of aggregation methods on final rankings of alternatives in the decision-making process. It is believed that a larger number of such real case studies can offer guidelines for choosing the appropriate aggregation method for the considered area of location problems.

One of the future research directions could be the development of software, which would enable the usage of a wider range of MCDM and fuzzy MCDM methods, as well as aggregation approaches and larger groups of experts.

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