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RESEARCH ARTICLE

An Integrated Approach of the AHP and Spherical Fuzzy Sets for Analyzing a Park-and-Ride Facility Location Problem Example by Heterogeneous Experts

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ABSTRACT Consensus is difficult to acquire among a group of transportation specialists with diverse areas of expertise over the most relevant set of criteria considering a transport related problem. For example, when establishing a Park-and-Ride (P&R) system, if an expert favors the public transport criterion, and another focuses on the economic area, the problem is considerably difficult to solve. Therefore, this research provides a methodological solution including the Analytic Hierarchy Process (AHP) and Spherical Fuzzy Sets (SFSs) with the purpose of addressing both sorts of difficulties concurrently, i.e., taking hesitant scores into account and synthesizing stakeholders' viewpoints through a mathematical procedure. SFSs are preferable compared to other solutions due to their flexible specification of the belonging function. In current study, the spherical AHP method is applied to a P&R system location problem to evaluate the results of the participating transportation experts from diverse backgrounds. Additionally, similarities and differences between the obtained results and the fuzzy AHP calculation are emphasized. Based on the results public transport accessibility is the most important criterion when establishing a P&R system. However, when compared to the AHP Triangular Fuzzy Sets multi-criteria technique, the sub-criteria vary significantly. The results give urban transport planners a clear guideline that the implementation of the P&R system should run in parallel with the optimization of public transport.

INDEX TERMS Park-and-ride, accessibility, analytic hierarchy process, spherical fuzzy set.

I. INTRODUCTION

Multi-criteria decision-making (MCDM) methods provide a tool that examines the level of consistency of the outcomes. From the various MCDM approaches AHP is ranked as one of the most popular methods, where it is recommended to include a consistency check to remove the incorrect solutions and incompetent evaluators by setting a cutoff value for the consistency ratio (CR) [1]. Those criteria whose scores are higher than the CR are deemed ineligible, while those whose scores are lower than the CR are approved. In the past few decades, numerous authors have examined the CR consistency metric and sought to improve it [2]. Despite these attempts, the metric has not fundamentally changed, and it continues to be utilized widely in AHP applications.

Even if consistency is maintained, several MCDM methods suggest that pure assessment scores are unreliable or less reliable than the values of survey analyses. In the AHP discipline, there is a range of methodological ways for addressing unreliable scoring, but fuzzy methods are the most frequent

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approaches [3]. In recent years, fuzzy AHP has been combined with other techniques like VIKOR and TOPSIS [4], yet the objective of fuzzification remains the same: to reduce the score uncertainty by assessing the environmental values linked with each score.

Recent techniques, known as the hesitant methods in AHP, take the decision-makers' assessments into account and determine the factors' final order of importance based on these uncertainties. When there are multiple sets of evaluators, one of the most vital components of the MCDM is the formulation of the final consensus priority of the alternatives or criteria [5]. Due to its pervasiveness, the issue of consensual prioritization of alternatives has a negative impact on multiple AHP methods. Moreover, dithering is capable of resolving this issue as it is applied not merely to individuals but to stakeholder groups to reach a broad consensus.

In the field of transportation, MCDM methods are applied to determine which parts of planning for a mode of transportation are most crucial. In addition to determining the users' preferences about the way of traveling alternatively, it is possible to ascertain these preferences. On the other hand, there is a dearth of knowledge regarding the considerations made by the experts for implementing a P&R system. To reduce inaccuracy, it is necessary to create expert groups and apply a combination of MCDM techniques, because the experts have different policy aims, and their weighting varies likewise.

In most cases, the creation of Park-and-Ride (P&R) facilities requires the participation of a significant number of professionals with a specialized field of expertise. The involvement of the groups depends on their level of interest and motivation in transportation development. Therefore, it is essential to establish a specific categorization system. The AHP method can classify the respondents as the followings: (a) planners whose primary focus is the P&R system, (b) planners whose primary issue is the reduction of air pollution in the city, and (c) planners whose fundamental concern is other aspects of the transportation infrastructure. Despite this categorization, uniformity cannot be guaranteed, and the likelihood of erroneous and misleading ratings remains fairly high [6].

Current research aims to develop a method that aids the establishment of agreement within a specialized group over the location of a P&R system. Saaty's scale, which serves as the basis for the original AHP scale, is the basis for the following three sorts of score values assessed during the consensus formulation procedure: membership, non-membership, and skepticism. In addition to the imprecise estimates, the method includes fuzzy values, which increase the dependability of the results. The proposed methodology is illustrated through a case study involving transportation planners in designing a P&R system. Furthermore, a group-based study of transportation professionals is performed to investigate the P&R facilities.

The remaining paper is structured as follows. Section II analyzes studies on MCDM approaches and P&R systems. Section III details the methodology including spherical fuzzy sets (SFSs) and the extension of AHP with SFSs. Section IV describes the case study and explains the criteria for the P&R system location problem. Section V demonstrates the results. Section VI provides a comparative analysis between the AHP and the Triangular Fuzzy Sets and the AHP and the SFSs approaches. Section VII presents the discussion. Finally, the conclusion in Section VIII summarizes the findings and the possibilities for future studies.

II. LITERATURE REVIEW

Numerous academics argue that the classic AHP method is insufficient for evaluating real-world scenarios due to linguistic uncertainty. By combining objective and subjective factors, a decision super matrix is constructed to yield exhaustive criterion scores [7]. The researchers develop an integrated AHP methodology based on the Buckley fuzzy set with Z numbers to estimate social sustainability improvement factors, where Z is an ordered pair of fuzzy numbers, where A is a fuzzy subset of the X-domain of variable Z, and B is a fuzzy subset of the unit interval [8]. The AHP requires the evaluators to evaluate pairwise comparison matrices due to the complexity of developing criteria for the associated problem. All evaluators can estimate their assessments by using various kinds of preference representations, such as interval preference relation, linguistic framework, and fuzzy preference relation [1]

A precise numeric value cannot transmit imprecise information on the evaluators' preference level. Thus, the fuzzy set theory is created to account for the ambiguity-related uncertainty [9]. In terms of set membership, imprecise data (e.g., fuzzy triangular numbers, trapezoidal fuzzy numbers) are analyzed. To resolve uncertainty and ambiguity in pairwise comparisons and to remove ambiguity and decrease uncertainty from the decision-making process, the fuzzy set and intuitionistic fuzzy set are combined [10]. The structure of the rules for type-1 fuzzy numbers and type-2 fuzzy numbers is similar with the exception of the antecedent and consequent. In addition, type-2 fuzzy sets generalize type-1 fuzzy sets, whereas type-2 fuzzy sets permit the introduction of uncertainty regarding the membership function in the fuzzy set theory. However, neither type-1 nor type-2 fuzzy numbers account for the degree of uncertainty when comparing two values [11].

The prospect of the fuzzy AHP development is explored. Saaty suggests a convective AHP strategy, which prioritizes the most important criteria and options as a fundamental and pragmatic method for addressing complex situations. This technique ranks the criteria and alternatives in a descending order of significance. The application of a hierarchical issue structure, the significance placed on the ratings, the absence of consistency, and the reliance on numerical pairwise comparisons are some of the flaws of AHP, which become apparent when this is taken into context [12]. Even if the scoring is accurate, there is still a chance that the total may incorrectly interpret the decision-makers' true intentions due to the incorrect scoring in the pairwise comparisons. This is possible regardless of whether the scoring is dependable. In an effort to find a solution to the scoring issues, over the history of the last four decades, numerous researchers have modified the AHP methodology to address some difficult MCDM issues in a wide variety of ambiguous contexts, such as combining the fuzzy AHP and TOPSIS [13], the fuzzy Delphi and AHP-DEMATEL [3], as well as the fuzzy AHP and fuzzy TOPSIS methods [14].

Over time, the AHP technique has been integrated with other approaches, such as AHP-HGDM, which makes the group choices as an extension of the AHP [15]. As a theoretical foundation for collective decision-making, the intuitionistic fuzzy AHP is created to express the evaluators' uncertain assessments [16]. A novel aggregation technique for merging individual intuitionistic fuzzy preference relations is developed [17]. In a study conducted by Kahraman et al [18], a new fluctuating fuzzy AHP approach is developed to address a warehouse location selection problem for a humanitarian organization by using fuzzy preference data with fluctuating levels of uncertainty. Within the framework of the interval valued intuitionistic AHP technique, a unique method for preference scaling is developed by utilizing the evaluators' linguistic judgements to address the multiple issues of AHP, such as ambiguity and vagueness. In the research conducted Kahraman et al [18], the pairwise comparison matrix is represented by intuitionistic fuzzy numbers with a degree of vacillation and interval-valued fuzzy numbers. Due to their inadequate expertise, evaluators may be unable to communicate their perspectives effectively while reviewing pairwise comparison judgments throughout the group decision-making process [19]. To solve this type of difficulty, a study [20] utilizes the neutrosophic set theory, which is effectively represented by a triangular neutrosophic number and specifies ambiguous, inconsistent, and incomplete information in respect to real-world challenges. The application of MCDM procedures is realized with a variety of criteria. Some of the many applications are listed that may be made by fuzzy sets, which have a contribution to the process of decision-making in terms of ambiguity: type-2 fuzzy sets [9], neutrosophic fuzzy sets [21], hesitant fuzzy sets [22], and Pythagorean fuzzy sets [23].

The P&R system works as a point of transition between personal cars and other public and private transport modes. A general trip from an origin to a destination utilizing the P&R system consists of traveling from the origin by a private vehicle, then parking the vehicle, and using other modes of transportation (e.g., public transport) to reach the destination, which is typically the business center [24]. Due to the fact that the P&R system functions as a modal interchange, the placement of these facilities within an urban setting must adhere to a number of criteria and sub-criteria [25]. These criteria are to be categorized and investigated by using MCDM approaches. In addition, a combination of these approaches can provide a solution to the issues of locating a P&R system. Several studies combined the AHP variables with the P&R system. Research reveals that the P&R might be incorporated into urban plans of cities as it offers sustainable mobility benefits [26]. This determination is made by applying MCDM methods, such as the AHP, and by taking the experts' opinions into account as part of the general framework for implementing P&R in medium-sized cities with congested city centers [27]. In addition, an investigation is done to analyze a variety of applications, including the P&R system, to attract private car users to public transport. The AHP is used to determine which variable has the most weight, and this procedure leads to the conclusion that implementing the P&R is the most excellent option for attracting individuals who already use public transport [28]. The optimal placement of the P&R facilities is consequently vital not solely for the users but for local governments, too. Thus, by using the AHP method, it is possible to analyze the following three crucial criteria: user coverage, accessibility from major roadways, and area availability. The results indicate that the AHP approach is an effective tool for evaluating and comparing the impact of various factors on each other and on the final outcome [29]. The AHP is also applied in a fuzzy environment, where fuzzy sets have the ability to deal with ambiguous notions in a particular manner. Furthermore, it can reduce the evaluators' thinking during decision-making. The challenge is structured to analyze a real-world issue in Cuenca, Ecuador [30].

To evaluate the group preferences for supplier selection, the fuzzy AHP for group decision-making under consensus achievement is used. In uncertain circumstances, the AHP technique does not account for the evaluators' uncertainty. In an uncertain, fuzzy context, the AHP approach solves this crucial issue by providing varying degrees of membership to remove the evaluators' hesitation. Similarly, the AHP in Pythagorean and intuitionistic environments takes the evaluators' indecision into account; however, the evaluators lack the power to resolve the indecision [31]. Due to the rapid evolution of the fuzzy set theory over time, the absence of a global perspective hinders the AHP technique in nearly all fuzzy environments. The recently discovered SFSs allow a degree of undecidability, a decision-maker's membership and non-membership to be allocated by satisfying the unit sphere condition [32].

In this study, the elaborated method includes an AHP extension in a fuzzy environment. This discloses the uncertainty assignment and provides the evaluator with a broad preference domain for making decisions. Current research presents the spherical AHP technique and its application to the challenge of deciding where a P&R system should be positioned.

III. METHODOLOGY

The novel concept of SFSs gives a larger preference domain for the decision-makers to define the membership degrees since the squared sum of the spherical parameters is allowed to be at most 1.0. Decision-makers can define their hesitancy information independently under a spherical fuzzy environment. SFSs are a generalization of Pythagorean fuzzy sets, picture fuzzy sets, and neutrosophic sets [32]. In the following, the definition of the SFSs is presented. SFS $\tilde{A}_S$. U_1 and U_2 represent two universes. Spherical sets $\tilde{A}_S$ and $\tilde{B}_S$ of this universe of discourse U_1 and U_2 is as follows:

$$\tilde{A}_S = \left\{x, \left(U_{\tilde{A}_S}(x), V_{\tilde{A}_S}(x), \pi_{\tilde{A}_S}(x)\right) | x \in U_1\right\} \tag{1}$$

where

$$U_{\tilde{A}_S}(x) : U_1 \rightarrow [0, 1], V_{\tilde{A}_S}(x) : U_1 \rightarrow [0, 1], \pi_{\tilde{A}_S}(x) : U_1 \rightarrow [0, 1] \tag{2}$$

And

$$0 \leq U^2_{\tilde{A}_S}(x) + V^2_{\tilde{A}_S}(x) + \pi^2_{\tilde{A}_S}(x) \leq 1 \forall x \in U_1 \tag{3}$$

For each x, the numbers $U_{\tilde{A}_s}(x)$, $V_{\tilde{A}_s}(x)$,and $\pi_{\tilde{A}_s}(x)$are the degree of membership, non-membership, and the hesitancy of x to $\tilde{A}_S$, respectively.

$$\tilde{B}_S = \left\{y, \left(U_{\tilde{B}_S}(y), V_{\tilde{B}_S}(y), \pi_{\tilde{B}_S}(y)\right) | y \in U_2\right\} \tag{4}$$

where

$$U_{\tilde{B}_S}(y) : U_2 \rightarrow [0, 1], V_{\tilde{B}_S}(y) : U_2 \rightarrow [0, 1], \pi_{\tilde{B}_S}(y) : U_2 \rightarrow [0, 1]$$

and

$$0 \leq U^2_{\tilde{B}_S}(y) + V^2_{\tilde{B}_S}(y) + \pi^2_{\tilde{B}_S}(y) \leq 1 \forall y \in U_2 \tag{5}$$

For each y, the numbers $U_{\tilde{B}_s}(y)$, $V_{\tilde{B}_s}(y)$,and $\pi_{\tilde{A}_s}(x)$ are the degree of membership, non-membership, and the hesitancy of y to $\tilde{B}_s$, respectively [9], [32] principle extends the classical arithmetic operations to their fuzzy corresponding. The extension principle is defined for single-valued SFSs. The proposed spherical fuzzy AHP method consists of the following steps as illustrated by Figure 1.

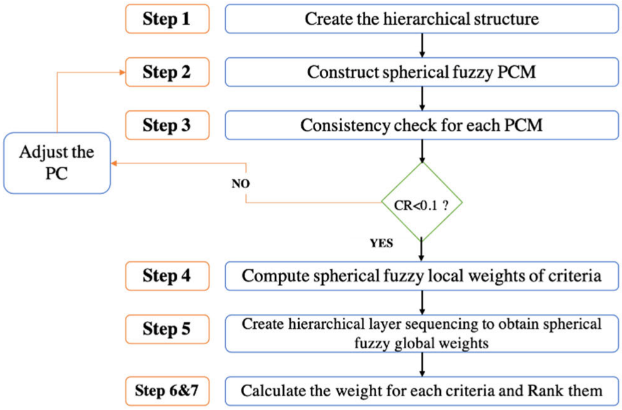

FIGURE 1. **The steps of the AHP with the SFSs method.**

Step 1: Construct the hierarchical structure of the complex problem.

TABLE 1. **The linguistic measures of importance used for pairwise comparisons.**

	(μ, v, π)	Score Index (SI)
Absolutely more importance (AMI)	(0.9, 0.1, 0.0)	9
Very high importance (VHI)	(0.8, 0.2, 0.1)	7
High importance (HI)	(0.7, 0.3, 0.2)	5
Slightly more importance (SMI)	(0.6, 0.4, 0.3)	3
Equal importance (EI)	(0.5, 0.5, 0.4)	1
Slightly low importance (SLI)	(0.4, 0.6, 0.3)	1/3
Low importance (LI)	(0.3, 0.7, 0.2)	1/5
Very low importance (VLI)	(0.2, 0.8, 0.1)	1/7
Absolutely low importance (ALI)	(0.1, 0.9, 0.0)	1/9

Step 2: Create pairwise comparisons by using spherical fuzzy judgment matrices based on the linguistic terms given in Table 1.

Equations (6) and (7) are utilized to get the score indices (SIs).

$$SI = \sqrt{\left|100 * \left[\left(U_{\tilde{A}_S} - \pi_{\tilde{A}_S}\right)^2 - \left(V_{\tilde{A}_S} - \pi_{\tilde{A}_S}\right)^2\right]\right|} \tag{6}$$

for AMI, VHI, HI, SMI, and EI.

$$\frac{1}{SI} = \frac{1}{SI = \sqrt{\left|100 * \left[\left(U_{\tilde{A}_S} - \pi_{\tilde{A}_S}\right)^2 - \left(V_{\tilde{A}_S} - \pi_{\tilde{A}_S}\right)^2\right]\right|}} \tag{7}$$

for EI, SLI, LI, VLI, and ALI.

Step 3: Check the consistency of each pairwise comparison matrix (PCM) (***J***). Therefore, convert the linguistic terms in the PCM into their corresponding SIs. Afterward, conduct the classical consistency check. The threshold of the CR is 10%.

Step 4: Calculate the spherical fuzzy local weights of the criteria and alternatives. Determine the weight of each alternative by using the SWAM operator given in Equation (8) with respect to each criterion. The weighted arithmetic mean is used to compute the spherical fuzzy weights.

$$\begin{aligned} SWAM_w(A_{S1}, \ldots, A_{Sn}) &= w_1 A_{S1} + w_2 A_{S2} + \ldots + w_n A_{Sn} \\ &= \langle [1 - \Pi^n_{i=1}(1 - U^2_{A_{si}})^{wi}]^{1/2}, \\ &\quad \times \Pi^n_{i=1} V^{wi}_{A_{si}}, [\Pi^n_{i=1}(1 - U^2_{A_{si}})^{wi} \\ &\quad - \Pi^n_{i=1}(1 - U^2_{A_{si}} - \pi^2_{A_{si}})^{wi}]^{1/2}\rangle \end{aligned} \tag{8}$$

where $w = 1/n$.

Step 5: Establish the hierarchical layer sequencing to obtain the global weights. Defuzzify the criteria weights by using the score function (S) in Equation (9), normalize them by Equation (10), and apply the spherical fuzzy multiplication given in Equation (11).

$$SI\left(\bar{w}_j^s\right) = \sqrt{\left|100 * \left[\left(3U_{\tilde{A}_S} - \frac{\pi_{\tilde{A}_S}}{2}\right)^2 - \left(\frac{V_{\tilde{A}_S}}{2} - \pi_{\tilde{A}_S}\right)^2\right]\right|} \tag{9}$$

Normalize the criteria weights by using Equation (10).

$$\begin{aligned} \bar{w}_j^s &= \frac{S(\bar{w}_j^s)}{\sum\limits_{J=1}^{n} S(\bar{w}_j^s)} \\ \tilde{A}_{S_{ij}} &= \bar{w}_j^s . \tilde{A}_{s_i} = \langle (1-(1-U_{\tilde{A}_s})^{\bar{w}}_{j^s})^{1/2}, V_{\tilde{A}_s}^{\bar{w}_j^s}, \\ &\quad \times ((1-U_{\tilde{A}_s})^{\bar{w}}_{j^s} - (1-U^2_{\tilde{A}_s} - \pi^2_{\tilde{A}_S})^{\bar{w}_j^s})^{1/2} \rangle \forall i \end{aligned} \tag{10}$$

The final spherical fuzzy AHP score ($\tilde{F}$) for each alternative Ai is obtained by carrying out the spherical fuzzy arithmetic addition over each global preference weight, as given in Equation (11).

$$\begin{aligned} \tilde{F} &= \sum_{j=1}^{n} \tilde{A}_{S_{ij}} = \tilde{A}_{S_{i1}} \oplus \tilde{A}_{S_{i2}} \ldots \oplus \tilde{A}_{S_{in}} \forall i \\ \text{i.e. } \tilde{A}_{S_{11}} \oplus \tilde{A}_{S_{12}} &= \langle (U^2_{\tilde{A}_{S11}} + U^2_{\tilde{A}_{S12}} - U^2_{\tilde{A}_{S11}} U^2_{\tilde{A}_{S12}})^{1/2}, \\ &\quad \times V_{\tilde{A}_{S11}} V_{\tilde{A}_{S12}}, ((1-U^2_{\tilde{A}_{S12}})\pi^2_{\tilde{A}_{S11}} \\ &\quad + (1-U^2_{\tilde{A}_{S11}})\pi^2_{\tilde{A}_{S12}} - \pi^2_{\tilde{A}_{S11}} \pi^2_{\tilde{A}_{S12}})^{1/2} \rangle \end{aligned} \tag{11}$$

Step 6: Defuzzify the final score of each alternative by using the score function (S) given in Equation (9).

Step 7: Rank the criteria with respect to the defuzzified final scores. The highest value indicates the best criterion.

IV. CASE STUDY

Through a case study, it is demonstrated how the elaborated methodology can be applied to the P&R system. The investigation is carried out in the Ecuadorian city of Cuenca, where a group of transportation specialists having diverse planning experience filled in a survey. The survey was conducted in May 2020 and the experts were chosen from the Municipality of the city of Cuenca. Figure 2 depicts a group of transportation specialists pursuing diverse planning goals. The average amount of time required by each expert to complete the survey was from 25 to 30 minutes. 25 distinct aspects of the P&R facilities are evaluated to establish the industry specialists' preferences and perspectives about the design of a P&R system (Figure 2).

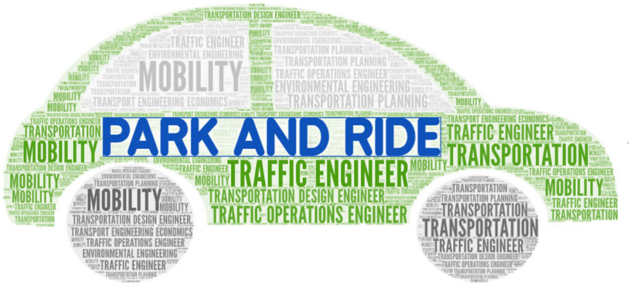

FIGURE 2. The aspects of transportation professionals for planning a P&R system.

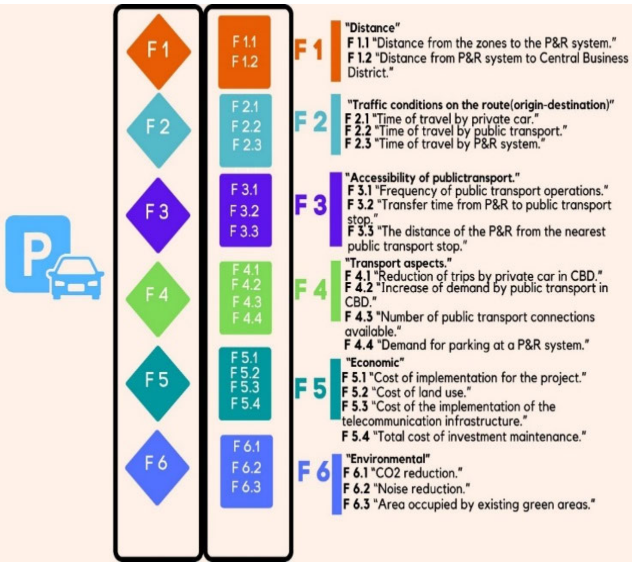

FIGURE 3. The hierarchical structure of the P&R facility location components [30].

The P&R facility location problem can be represented as a hierarchical structure. The criteria consist of a comprehensive review of the existing literature about how and why to implement a P&R system. These criteria are classified into two levels. Each criterion and its concept are depicted in Figure 3. Level 1 is comprised of 6 P&R system installation components (factors) that are usually recognized as being of utmost importance, such as distance, traffic conditions, accessibility of public transport, transport aspects, economic, and environmental criteria. Level 2 consists of a total of 19 sub-criteria that are secondary to the primary criteria. Each of these secondary criteria is connected to a primary criterion in some way [30].

V. RESULTS

This section shows the results of applying the proposed method.

Table 2 indicates the final integrated SPS weights for the main factors (F1 to F6). According to the results, criterion F3, which refers to the accessibility of public transport, is the most valued. Transportation specialists believe that when a new P&R system is established, it should include a connection to public transport. When designing a P&R system, the slightest consideration is given to F2, which is about the

TABLE 2. The final integrated spherical fuzzy weights for the main factors in case of level 1.

Level 1	Spherical Fuzzy Weights			Crisp Weights
F1	0.400	0.593	0.268	0.133
F2	0.308	0.688	0.245	0.099
F3	0.633	0.347	0.281	0.219
F4	0.589	0.409	0.263	0.204
F5	0.436	0.569	0.261	0.147
F6	0.575	0.411	0.290	0.197

TABLE 3. The final integrated spherical fuzzy weights for the sub-factors in case of level 2 of F2.

F2	Spherical Fuzzy Weights			Crisp Weights
F2.1	0.336	0.644	0.276	0.199
F2.2	0.590	0.418	0.263	0.375
F2.3	0.664	0.338	0.251	0.427

TABLE 4. The final integrated spherical fuzzy weights for the sub-factors in case of level 2 of F3.

F3	Spherical Fuzzy Weights			Crisp Weights
F3.1	0.646	0.349	0.277	0.439
F3.2	0.364	0.609	0.287	0.232
F3.3	0.496	0.501	0.285	0.329

TABLE 5. The final integrated spherical fuzzy weights for the sub-factors in case of level 2 of F4.

F4	Spherical Fuzzy Weights			Crisp Weights
F4.1	0.520	0.465	0.296	0.276
F4.2	0.519	0.460	0.311	0.274
F4.3	0.478	0.490	0.318	0.249
F4.4	0.390	0.586	0.294	0.200

TABLE 6. The final integrated spherical fuzzy weights for the sub-factors in case of level 2 of F5.

F5	Spherical Fuzzy Weights			Crisp Weights
F5.1	0.459	0.496	0.333	0.249
F5.2	0.514	0.440	0.338	0.282
F5.3	0.408	0.557	0.311	0.220
F5.4	0.453	0.518	0.305	0.248

TABLE 7. The final integrated spherical fuzzy weights for the sub-factors in case of level 2 of F6.

F6	Spherical Fuzzy Weights			Crisp Weights
F6.1	0.636	0.335	0.304	0.445
F6.2	0.460	0.525	0.295	0.313
F6.3	0.368	0.600	0.297	0.243

existing traffic situation from the origin to the destination. When implementing a P&R system, it is seen that specialists do not consider the traffic conditions. When examined in more detail, it is found that F4 aspects of public transport, which refer to setting the frequencies and travel stops, are necessary for constructing a P&R system. These findings support previous outcomes regarding the fact that the P&R system should be connected to public transport [33], [34].

The connection between the sub-criteria and the principal criterion F2 pertaining to traffic when using the P&R system is outlined in Table 3. In this case, the F2.3 criterion is about the overall amount of time spent on traveling. This factor is more important than F2.1, which refers to a trip made exclusively by a private vehicle. From this perspective, it is important that the location of the P&R system does not increase the journey time [35].

Table 4 shows the interaction between the sub-criteria belonging to F3. The most important criterion in this context is F3.1, which refers to the frequency of public transport operation. It is essential to understand that the term connectivity refers to the regularity with which public transport operates around the P&R system.

Regarding the transport aspects listed in Table 5, the F4.1 criterion aims at reducing the number of cars in the central business center of cities. The professionals plan to reduce the number of cars by using P&R system [36], [37].

Table 6 identifies which sub-criterion is important considering criterion F5 (economic). F5.2 is referring to the cost of the land for locating a P&R system is the most important since it is located in a city, where structures have already been constructed. The implementation of the networking infrastructure is the least significant, and it is evident that it may be accomplished over time.

The primary criterion F6 (environment) is divided into three sub-criteria, which are presented in Table 7. The most important requirement is F6.1, which aims at a reduction in CO2 emission levels. According previous research [38], the P&R system has the potential to reduce air pollution because fewer cars travel to the central business center.

Afterward, Individual Judgment Aggregation is used where the weighted geometric mean of the individual values is calculated. The aggregation generates a group matrix from the identical entries of the individual PCMs and applies the AHP approach to acquire the weight vectors. To calculate the global weights for each criterion and sub-criterion, the local weights of each level are multiplied by the local weights of each sub-criterion. After this multiplication, it may be used to normalize the global weights of the criteria and to estimate the final weights, as shown in Table 8.

TABLE 8. The ranking of the factors in case of level 1.

Factors	Weights	Rankings
F1	0.133	5
F2	0.099	6
F3	0.219	1
F4	0.204	2
F5	0.147	4
F6	0.197	3

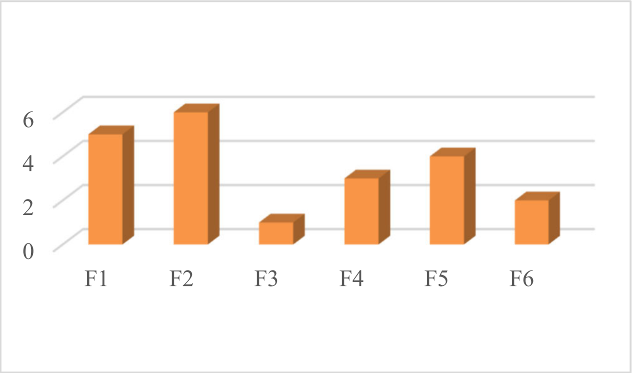

FIGURE 4. The ranking of the primary criteria.

Furthermore, the ranking of the primary criteria is visually depicted in Figure 4. The accessibility to public transport is the primary criterion for developing a P&R system.

Table 9 outlines the criteria for implementing a P&R system along with the aggregated ratings of the sub-factors.

The results reported in Table 9 indicate that the relationship between the areas and the P&R system, designated by F1.1, and describing the geographical location of the facilities is the most important Level 2 criterion. Given that the P&R system is tied to the public transport system, it is evident that F3.1 refers to the frequency of public transport operations. While F2.1, which is the travel time by private vehicle, is the least significant element, which should not be surprising given that a P&R system must initially be connected to the public transport network, regardless of private vehicle use, to function properly.

VI. COMPARATIVE ANALYSIS

This section discusses the outcomes of applying the methods in the article "Analytic Hierarchy Process and Triangular Fuzzy Sets" [30] compared to the results of current research. The AHP is a well-known method for solving complex decision issues, and is based on an additive weighting procedure, where a variety of significant criteria are represented by their relative relevance levels. Academics and practitioners in various fields use AHP for a wide range of problems, most notably in engineering-related fields, such as transportation engineering [39], [40].

TABLE 9. The ranking of the factors in case of level 2.

Factors	Local Weights	Local Rankings	Global Weights	Global Rankings
F1.1	0.741	1	0.099	1
F1.2	0.259	2	0.034	17
F2.1	0.199	3	0.020	19
F2.2	0.375	2	0.037	14
F2.3	0.427	1	0.042	11
F3.1	0.439	1	0.096	2
F3.2	0.232	3	0.051	9
F3.3	0.329	2	0.072	4
F4.1	0.276	2	0.056	6
F4.2	0.274	1	0.056	7
F4.3	0.249	3	0.051	8
F4.4	0.200	4	0.041	13
F5.1	0.249	2	0.037	15
F5.2	0.282	1	0.042	12
F5.3	0.220	3	0.032	18
F5.4	0.248	4	0.037	16
F6.1	0.445	1	0.088	3
F6.2	0.313	2	0.062	5
F6.3	0.243	3	0.048	10

TABLE 10. The weight scores for the P&R facilities of the main criteria in case of level 1 [30].

Criteria	Rankings
F1	5
F2	6
F3	1
F4	3
F5	2
F6	4

The AHP and Triangular Fuzzy Sets are applied in the research that was carried out by Ortega [30] to evaluate the proposed criteria for the P&R location problem. The results of the ranking of the criteria, which can be found in Tables 10 and 11, are not the same as the results obtained in current research by using the AHP and the SFSs approaches.

When comparing the most important criteria in Tables 8 and 10, it can be seen that in both cases, the most important is F3, which pertains to the accessibility of public transport. There are three primary criteria (i.e., F1, F2, and F3) that have the same rankings once using the two techniques. The first difference is in the case of criterion F4, which is about the transportation aspects. The technique used in current article places this criterion the second position of the ranking (Table 8), but the results demonstrated in Table 10 show that this criterion has the third position. The most significant variation between the results of the two techniques is that criterion F5, which analyzes economics, is placed the second position in the ranking presented in this article, but in Table 10, it has the fourth position. This is essential to note since it illustrates that the ranking of the criteria may vary

TABLE 11. The weight scores for the P&R facilities regarding the sub-criteria in case of level 2 [30].

Factors	Rankings
F1.1	5
F1.2	18
F2.1	19
F2.2	13
F2.3	11
F3.1	1
F3.2	8
F3.3	3
F4.1	7
F4.2	4
F4.3	9
F4.4	17
F5.1	14
F5.2	12
F5.3	15
F5.4	16
F6.1	2
F6.2	6
F6.3	10

according to the applied MCDM method. Specifically, based on the findings of current study, it can be concluded that the cost of installing a P&R system has a significant influence to establish the system. It suggests that among the diverse collection of transportation specialists in the study group for current research work, there are transportation engineers who have an emphasis on economics.

When analyzing the sub-criteria, the disparity between the various MDCM techniques becomes apparent. Comparing Tables 9 and 11, it can be seen that the most relevant criterion in Table 9 is F1.1, which represents the distances between the zones and the P&R. On the other hand, the results of Table 11 show that the most essential criterion is F3.1, which is about the frequency of public transport. The least significant entry in both Tables 9 and 11 is F2.1, which deals with the journey time by private vehicle.

These results justify the idea that current article offers a contribution to the topic. It is likely that the criteria and sub-criteria of the conducted survey have different weights based on the experts' priorities, and it varies based on the applied MCDM method, as well. However, the provision of public transport accessibility remains the single most important factor in both cases.

VII. DISCUSSION

Given the reported data, it is evident that the SFS method contributes to the process of achieving consensus among various stakeholder groups. As described, the competing groups of stakeholders have varied ranges of priorities, and without application of the method, consensus could be only achieved through another round of voting, negotiation, or subjective weighting. In our case, the evaluators decide on their confidence regarding the scoring not merely inside the particular group but when all groups are considered. In addition, the defuzzification process plays an essential part in determining the weights of the criteria, but it has not been extensively investigated in the literature as the SFSs have been recently presented. The revised definitions of the defuzzification formula may result in modest variations in the weights of the criteria, but the formula is not required until the final step. In the research, the situation of consensus-based prioritization is presented, which ensures that the extreme position of a single stakeholder cannot change the majority of responses, while other opinions are still considered, and the status quo is maintained.

When comparing two methods, it can be asked which technique is superior. According to the results shown, this AHP method is appropriate because it reduces the unpredictability associated with the various criteria developed when establishing a P&R system. In other words, whether the criteria can differ based on the level of the transportation expert's expertise, is affirmative. It is recommended to adopt the method presented in this article when applying MCDM to a group of specialists with different backgrounds.

In current study, one of the limitations is that the research is conducted in a Latin American city. It would be useful to know whether the results would alter significantly if there were various kinds of transportation specialists as well as different cities, countries, and continents involved. As in case of any approach, the offered solution has disadvantages, as well. In its current form, the method cannot discriminate the weights of the fixed groups involved in the choice a priori.

VIII. CONCLUSION

The objective of this study is to develop a new method of SFSs, which allows the detection of uncertain and less certain answers as well as the creation of consensus among various groups of evaluators with different motivations, interests, or information related to a decision problem. To achieve this goal, AHP is extended with SFSs in current research. In accordance with the principles of the spherical fuzzy logic, the features of the proposed method make it possible to not merely account for uncertain or imprecise scores through the process of fuzzification but to synthesize the variety of perspectives through the treatment of the groups as individuals in the overall calculation. The SFS is a powerful concept to cope with uncertainty issues by presenting a wider decision-making area and identifying hesitancy.

In addition, comparative research is conducted to demonstrate the dependability of the method. According to the results, each method offers a distinct classification of the criteria. It is discovered that the variation in the answers is proportional to the groups' degree of heterogeneity. The method provides the decision-makers with access to a broader domain of membership function definitions, which is the primary benefit of applying this strategy.

This article clarifies that the weight assigned to each criterion varies based on the use of a particular MCDM technique and takes each participant's level of experience into account. In the future, the Parsimonious Best Worst [43] can be adopted and compared with the gained results, also the groups should be categorized according to country, continent, and city type. Afterward, based on the specialists' knowledge as well as the country and continent, it can be determined which criteria are essential for establishing a P&R system.

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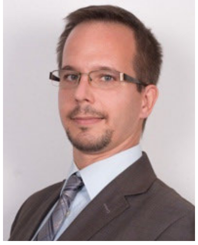

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