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Sustainable development solutions of public transportation:An integrated IMF SWARA and Fuzzy Bonferroni operator

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ABSTRACT

Developing the quality of public transport has an efficient impact to attract more users to switch modes from private vehicles to public transport, which has a tremendous capability in reducing the traffic congestion, noise and CO2 emissions the urban areas. For this reason, policy makers and scholars aim to enhance the supply quality of public transport system, where involving citizens along with experts and decision makers in the decision process will reflect the existed and future demand to provide more sustainable solutions which provide efficient solutions to achieve positive impacts on the local environment. This study intends to determine the preference of decision-makers and operators for the importance of the supply quality elements of urban bus transport services in Mersin city, Turkey. For this aim, decision makers and experts are involved in the evaluation process to provide feedback on public transport quality with the view of increasing the satisfaction and thus usage, with positive impacts on increased public transport modal share and dropped CO2 emission transport. In total we have formed list of three main criteria: transport quality, service quality and traceability which contains in total 21 sub-criteria. For determining all criteria weights we have formed in total 112 models using IMF SWARA (Stepwise Weight Assessment Ratio Analysis) method and for final determining criteria weights Fuzzy Bonferroni operator (FBO) has been used. Applying such model we have ensured stability in final values of criteria and have obtained optimal results based on preferences decision makers. The adopted results show that the most significant attribute in the system is the "Traceability" with highest weight score (0.398), followed by the "Transport quality" with weight score (0.334), however, the service quality rank as the last significant attribute with weight score (0.264). The originality of our work is conducting IMF SWARA method for improving the service quality of the public transport system.

1. Introduction

Scholars and transport experts indicate that the growth of population and commercial activities accumulation will augment the demand towards mobility and influence the environment negatively in the cities (Sadorsky, 2014; Jain and Tiwari, 2016). The proposed solutions have to be efficient and sustainable solutions, for example, shifting to use electric vehicles impacts the environment negatively through electricity generation and at same time is does not solve traffic congestions problem in cities (Eccarius and Lu, 2020). To achieve lower impact of the carbon mobility from citizens movements, citizens have to shift to public transport. The system of public transport holds the cities providing abundant and sustainable service. However, an efficient transport system is a critical manner for attracting citizens to use public transport system alleviates the travel numbers with private cars which interns reduces traffic congestion, noise, CO2 emissions air pollutants in an efficient way in cities (Borck, 2019; Jia, 2021; Wimbadi et al., 2021).

To reduce traffic congestion, noise, CO2 emissions air pollutants in an efficient way in cities, it is important to enhance the supply quality of the public transport system. Enhancing transit provision is increasingly seen as a critical item in the policy package that targets to decrease car dependency by stimulating mode transferring from private vehiecles to public transport systems (Brons et al., 2009; Lindsey et al., 2010). Furthermore, enhancing public transit services per se, regions imped to transit stations are often incorporatedd with transit-oriented development (TOD) with higher density, diverse land utilises, and improved

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pedestrian environment, which conducts a greater propensity for non-motorized journies (Chatman, 2013; Ewing and Hamidi, 2014). In addition, transit infrastructure is significant in influencing travel behavior (Taylor et al., 2009). Because of the elevated construction, the maintenance of thrifty transit fare appoints important challenges on transit operators to raise users number (Zhao and Levinson, 2012).

Developing public transport service quality to attain sustainable improvement in urban transport has become one of the critical and sensitive precedencies in urban rising (Gündoğdu et al., 2021; Simić et al., 2022). Several works spotted the light on the most significant criteria related to service quality of public transport, for instance, reliability (Soza-Parra et al., 2019), safety (Shiwakoti et al., 2019), approachability (Saif et al., 2019; Miao et al., 2019) and directness (Jin et al., 2019; Duleba et al., 2021).

Previous studies measure the related criteria for public transport service quality by different perspectives. For example, some studies estimated the safety taking into consider road accidents, where public transport considers a safe mode choice for users than other types (Truong and Currie, 2019). However, regarding the crime, users have negative impacts and they prefer using their private cars (Delbosc and Currie, 2012). In order to come over this issues, policy makers and operators have to provide efficient solutions to make the users not avoiding public transport. For evaluating the related criteria to improving the service quality of public transport system, several approaches have been applied, such as, linear regression, structural equation model, correlation analysis and decision support methods. The structural equation model (SEM) employed by Shen et al. (2016) to estimate the significant criteria that impacts user's satisfaction. As a scale of the development, Mahmoudi et al. (2010) adopted correlations between users' perceived service quality and total satisfaction. However, recently, the application multi criteria decision making (MCDM) approaches got significantly increased for evaluating transport complex systems (Moslem and Çelikbilek, 2020; Moslem et al., 2020; Vrtagić et al., 2021; Eren and Katanalp, 2022; Elmansouri et al. 2022).

Our study aims to highlight the preference of decision-makers and operators for the importance of the supply quality elements of urban bus transport services. For this aim, first we created a suitable structure for the public transport service quality based on experts point of view in the related field and also considering the literature, then we developed an efficient model to estimate this complex problem. The integrated model in this study is the IMF SWARA and Fuzzy Bonferroni Operator.

Practical problems, and especially quality assessment, very often need the application of precise MCDM models which treat uncertainty in adequate way. The novelty of our work is conducting IMF SWARA method for improving the service quality of the public transport system. IMF SWARA method has many advantages in comparison to other MCDM methods: it consists of only five simple steps, uses an appropriate scale for evaluation criteria (which is not the case in fuzzy SWARA), uses simple fuzzy operations among own steps, possibility to calculate weights which are more precise in comparing to other methods because use a predefined scale which is developed in the purpose of this method. The fuzzy Bonferroni operator is the appropriate operator for group decision-making as is the case in this paper.

This research is structured as follows: Section 2 presents the methodology. Section 3 defines the investigated problem. Section 4 provides the results and discussion. Section 5 gives the conclusions of the study.

2. Litrature Review

2.1. The supply quality of public transport

Developing the supply quality of public transport considers important function to accure the pleasue level of the users and at same time it is a significant factor to attract more private vehicle users, which leads to a significant decreasing in environment and congestion problems in cities. Transport scholars have investigated travel pleasure with public transport as the overall level of attainment with users' demand and expectation (Tyrinopoulos and Antoniou, 2008), the attainment of demand and the result of cumulative and single empiricisms. The most negative public transport prectices have been illustrated to be exceptionally memorable (Friman and Fellesson, 2009). Fornell (1992) evaluated the quality of service and users expectations and satisfaction, where satisfaction level was the focal point of the operator and policy maker, the study neglected users' point of view in the evaluation process.

The link between user satisfaction and service quality has been broadly controversial, indeed user satisfaction is essentional because it shows whether users like the service that the company is providing. The allegation that an increment in supply spearheading to pleasure Amelioration has demonstrated to have its defenders (Barabino et al., 2012). However, there is an overall convention that an increment in general satisfaction leads to an increment in user loyalty, which can generate user retention and thus have long term impacts in terms of sustainable mobility and reduced traffic emissions. Data on subjective users preferences is in general gained by user satisfaction questionnaires (at stops, on - board, online), whereas objective performance scales are applied by automated data gathering tools and mystery shopping questionnaire surveys.

In addition, several factors related to supply quality of public transport have been identified by transport scholars. Guirao et al. (2016) highlighted the frequency, punctuality, as the most relevant service quality factors related to public transport, for instance, continous experiences of the buses that are not on time will leads to unsatisfactory and unreliability with the provided service. Eboli and Mazzulla (2009) evaluated eleven main criteria to spot the light on check passenger satisfaction towards public bus transport and they detected the on-board security and reliability as the most significant factors related public transport service quality, however, the results were mainly generated from users' point of view and experts opinion was absent in evaluation process, they adopted numerical scale in computation process, this scale has allows the analysis of quantitative approaches. Moreover, Cantwell et al. (2009) spotted the reliability of the system, comfort at stops and waiting time at stops as the most valued service quality factors related to public transport. Çelikbilek et al. (2020) also found the reliability is the second most desired factor for developing the public transport service quality after travel time and awaiting time. Alternatively, Dell'Olio et al. (2011) indicated to the difference between the precieved quality and the desired quality of public transport system, the reason comes from users' expections and from their daily experience, in this study the comfort was spotted as the most significant factor related public transport service quality for users group over 65, while it was detected that the cleanliness and security factors are the most significant factors related public transport service for woman side (Yavuz and Welch, 2010; Dell'Olio et al., 2011).

Alternatively, Thompson and Schofield (2007) defined frequency of travel and time on-board as key factors for the service quality measure. The ease of buying tickets, on - board security and reliability are regarded are the most essential criteria in predominantly transporting student commuters (Eboli and Mazzulla, 2009). However, from non-users group point of view the comfort was most relevant factor (Dell'Olio et al., 2011). Mouwen (2015) spotted an interesting difference in satisfaction level between young users group and over 65 users group, where for over 65 group the satisfaction was clearly higher than young users group. Duleba, and Moslem (2018) evaluated the preferences of users and non-users groups towards imperoving public busb-transport system and they found no significant difference between them, where the safety of travel was reported as the most essential factor for both groups, however, the least important factor was different for each gropu, where travel time was the least essential factor for users group while for non-users group the approachability was the least important factor.

Transport researchers have conducted a variety of approaches (e.g., structural equation models, stated preferences or multiple regression analysis) to investigate the supply quality of public transport, where the stated preference method is a flexible approachand provides information about the economic benefits and also it offers the identification of the user's demand, however, the multiple regression analysis help scientists to evaluate the relative influences and it elevate the reliability through avoiding the dependency, but in the same time the application consume time and efforts to analyse the problem and generate the results. Friman et al. (2001) applied structural equation model (SEM) and illustrated how the experience of continousaly changing and deviating adverse encounters influence satisfaction with service factors and the overall journey pleasure, the SEM model considers an explicit assessment of scaleing error and it testing the fit of the model to the collected data. Eboli and Mazzulla (2009), also employed SEM to estimate the relationship among cumulative satisfaction and service quality attributes, since SEM cinsiders an efficient tool to detect the hypothetical realtionships in social science. De Oña and de Oña (2014) conducted path analysis and neural networks to estimate the service quality of public transport, where the path analysis considers an efficient technique to easier prioritization and it improves the accurency of the results as well, however, the adopted neural networks has a foreseen advantage because of the conducted complex algorithms. Ettema et al. (2012) adopted regression analysis in order to estimate service quality factors and spotted the users preferences toward the journey in the daily activities. Duleba and Moslem (2019) employed decision making support approach with pareto optimality to ameliorate the urban bus transport supply quality, the employed mulit criteria analysis supports complex decisions, through a clear specifiying of the criteria and alternatives.

2.2. Applications of fuzzy MCDM models in transport

The IMF SWARA method has been developed by Vrtagić et al. (2021) to evaluate road infrastructure from the aspect of traffic safety. In the fields of transport and traffic have been implemented only in a few studies. Similar research to the original paper on IMF SWARA method has been performed by Damjanović et al. (2022), where study aimed to determine the impact of vehicles on the level of traffic safety in Montenegro between 1998 and 2020. This method has been combined with DEA (Data Envelopment Analysis) and MARCOS methods to obtain periods with a high level of safety. Other two studies related to transport are with implementation in dangerous goods (Vojinović et al. 2021) and logistics (Zolfani et al. 2021). Vojinović et al. (2021) have implemented the IMF SWARA method in combination with the Rough MCDM model to evaluate 11 companies for transporting hazardous goods based on nine criteria belong to various group. These values have been calculated using IMF SWARA method. Zolfani et al. (2021) integrated the IMF SWARA method with Fuzzy MABAC to assess eight logistics villages according to nine essential factors. These potential variants are a very important distribution of goods in the whole transportation chain. IMF SWARA has been extended with Z numbers in (Stević et al. 2022) to make ranking among four information technology for order picking. This important task in logistics has widely present in storage, distribution centers, logistics centers, etc. IMF SWARA based on Z numbers has been integrated with the Fuzzy EDAS-Z method, and results show that pick to vision is the best solution.

Fuzzy FUCOM method has been exploited in many different areas in different forms, but it is also found in the transport field. Pamučar et al. (2021) have applied fuzzy FUCOM and neutrosophic fuzzy MARCOS model to evaluate alternative fuel vehicles to achieve sustainable transport. Results show that electric vehicles are the most suitable solution for solving sustainable problems. Fuzzy FUCOM has been used to compute 20 criteria weights structured into five groups with a nonequal hierarchy structure. Demir et al. (2022) have performed research related to sustainable urban mobility plans in Montenegro, in the city of Podgorica, using a combination of Fuzzy FUCOM and Fuzzy CoCoSo methods. They used 23 criteria divided into five main groups to evaluate strategies that will ensure sustainable mobility in urban areas. A similar study related to urban mobility in Turkey has been performed in the paper (Pamucar et al., 2020), where the authors rank transportation demand management (TDM) measures. Fuzzy FUCOM has been applied in integration with Fuzzy Bonferroni and Dombi operators, and results show that is public transport capacity improvements the best alternative among those considered. Ayadi et al. (2021) have selected a logistics platform from a sustainable aspect using the integration of different MCDM methods, from which Fuzzy FUCOM has been used to determine the significance of 15 criteria structured in five groups.

Fuzzy PIPRECIA method has been used in several studies related to the transport field. In the paper (Bakır et al., 2021), this method has been used for determining criteria weights for aircraft selection from a regional aspect. The MCDM model has been formed according to 14 criteria and six variants in group decision-making. Results showed that the most important criterion for aircraft selection was operational costs. Vesković et al. (2020) applied fuzzy PIPRECIA in order to calculate criteria coefficients for the assessment of the reach stacker for the container terminal located in Belgrade. They formed a list of 15 criteria divided into three main groups in an equal hierarchy structure. They have concluded that the technological group of criteria represents the dominant group because three criteria from this group are in the first position (manipulative abilities), the second (lift height), and the third position (number of the processed TEU in the unit of time). Memiş et al. (2020) have created MCDM model using fuzzy PIPRECIA in a group decision-making process for ranking road transportation risk. Eight DMs involved in their research made an assessment of ten criteria formed according to the literature review. Their obtained results show that transport infrastructure-based dangers and risks related to waiting at the customs gate are the most essential. Pamučar et al. (2022) have formed a novel approach, including fuzzy PIPRECIA method. They introduced D numbers in the procedure of this method and used them for evaluating green strategies in mobility planning. 16 various criteria have been assessed using the novel algorithm to make more precise weights for further ranking four green strategies. Ulutas et al. (2021) used a hybrid method for determining criteria weights for the selection of transportation company for the distribution of goods or, as in the literature well-known term logistics provider. Weights obtained using the Fuzzy PIPRECIA method have been averaged by weights with the Fuzzy PSI method in order to get final values. Cost of service has been identified as a criterion with the largest influence on a decision on which transportation company should be chosen. Fuzzy PIPRECIA has been used to quantify previously performed SWOT analysis in transport company in Bosnia and Herzegovina. The aim of that study (Đalić et al. 2020) was a quantitative SWOT analysis to further develop strategies that can help realize increasing competitive advantages in the international market where this transportation company operates. To estimate risk levels at a railway crossings (Blagojević et al. 2021) carried out Fuzzy FUCOM for determining criteria values, while fuzzy MARCOS has been used for ranking railway crossings.

3. Methodology

The applied methodology for evaluating public transport supply quality and a complete diagram of flow research have been shown in Fig. 1. First, we have formed a list of appropriate criteria and subcriteria that are essential for public transport users and for interviewed experts. In the second stage, we formed questionnaires related to the formed list of criteria and sent them to decision-makers (DMs) to make the assessment. The third phase represents the application of IMF SWARA and FBO to obtain final criteria weights and make the appropriate rankings. Finally, we have performed discussion and conclusion remarks according to obtained results.

According to elaborated studies in background section can be concluded that all three methods: IMF SWARA, Fuzzy FUCOM, and Fuzzy PIPRECIA, have huge applications in the field of transport or

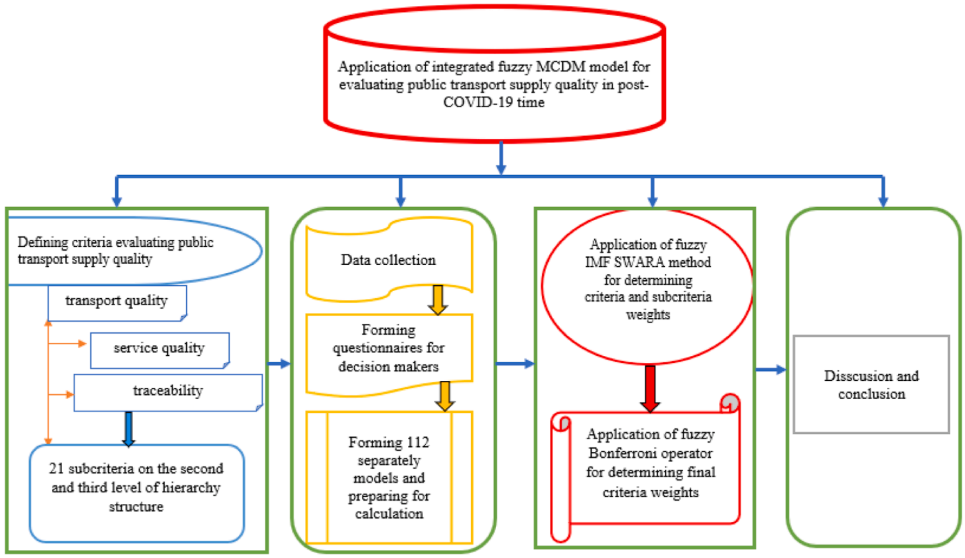

Fig. 1. Diagram of research flow.

similar areas. However, they never have been applied in one integrated model, as the case in this paper. For averaging criteria weights obtained using the IMF SWARA method, we have used Fuzzy Bonferroni operator for all levels of the hierarchical structure of the MCDM model. For verification and checking obtained results using IMF SWARA, we have applied Fuzzy FUCOM and Fuzzy PIPRECIA methods.

3.1. *IMF SWARA method*

Vrtagić et al. (2021) defined IMF SWARA method. The algorithm is presented below (Vojinović et al., 2022):

Step 1: Identification set of criteria, and sorting it from most significant to least significant (Puška & Stojanović, 2022).
Step 2: Applying a sorted list, it is performed a comparison of (Cj) in relation to (Cj−1), which is actually $\overline{s_j}$. An appropriate TFN (Triangular Fuzzy Number) scale that facilitates the comparison of criteria by IMF SWARA is given in Fig. 2.
Step 3: Determination of the fuzzy coefficient $\overline{k_j}$ (1):

$$\overline{k_j} = \begin{cases} \overline{1} & j = 1 \\ \overline{s_j} \oplus \overline{1} & j > 1 \end{cases} \tag{1}$$

Step 4: Determination of the weights $\overline{q_j}$ (2):

$$\overline{q_j} = \begin{cases} \overline{1} & j = 1 \\ \dfrac{\overline{q_{j-1}}}{\overline{k_j}} & j > 1 \end{cases} \tag{2}$$

Step 5: Calculation of the final weights w_j:

$$\overline{w_j} = \frac{\overline{q_j}}{\sum_{j=1}^{m} \overline{q_j}} \tag{3}$$

where m is number of criteria.

3.2. *Fuzzy Bonferroni operator*

The fuzzy Bonferroni aggregate was used by Yager (2009) and Pamucar (2020).

Linguistic Variable	Abbreviation	TFN Scale		
Absolutely less significant	ALS	1.000	1.000	1.000
Dominantly less significant	DLS	½	2/3	1.000
Much less significant	MLS	2/5	1/2	2/3
Really less significant	RLS	1/3	2/5	1/2
Less significant	LS	2/7	1/3	2/5
Moderately less significant	MDLS	¼	2/7	1/3
Weakly less significant	WLS	2/9	1/4	2/7
Equally significant	ES	0.000	0.000	0.000

Fig. 2. Scale for evaluation the criteria using IMF SWARA method.

$$\widetilde{a}_{ij} = \left(a^l_{ij}, a^m_{ij}, a^u_{ij}\right) = \begin{cases} a^l_{ij} = \left(\dfrac{1}{e(e-1)} \sum\limits_{\substack{i,j=1 \\ i \neq j}}^{e} a^{lp}_i \otimes a^{lq}_j\right)^{\frac{1}{p+q}} \\ a^m_{ij} = \left(\dfrac{1}{e(e-1)} \sum\limits_{\substack{i,j=1 \\ i \neq j}}^{e} a^{mp}_i \otimes a^{mq}_j\right)^{\frac{1}{p+q}} \\ a^u_{ij} = \left(\dfrac{1}{e(e-1)} \sum\limits_{\substack{i,j=1 \\ i \neq j}}^{e} a^{up}_i \otimes a^{uq}_j\right)^{\frac{1}{p+q}} \end{cases} \quad (4)$$

e is the number of experts, while $p, q \geq 0$ are non-negative numbers.

3.3. Fuzzy FUCOM method

Algorithm (Pamučar and Ecer, 2020; Vesković et al. 2022)

Step 1. Identification of criteria.
Step 2. Sorting it from most significant to least significant.

$$\overline{C}_{j(1)} > \overline{C}_{j(2)} > \ldots > \overline{C}_{j(k)} \quad (5)$$

Step 3. Fuzzy comparative significance $\overline{\varphi}_{k/(k+1)}$ should be determined.

$$\overline{\varphi}_{k/(k+1)} = \frac{\overline{\varpi}_{C_{j(k)}}}{\overline{\varpi}_{C_{j(k+1)}}} = \frac{\left(\varpi^l_{C_{j(k)}}, \varpi^m_{C_{j(k)}}, \varpi^u_{C_{j(k)}}\right)}{\left(\varpi^l_{C_{j(k+1)}}, \varpi^m_{C_{j(k+1)}}, \varpi^u_{C_{j(k+1)}}\right)} \quad (6)$$

A fuzzy vector of comparative importance is obtained.

$$\overline{\Phi} = \left(\overline{\varphi}_{1/2}, \overline{\varphi}_{2/3}, \ldots, \overline{\varphi}_{k/(k+1)}\right) \quad (7)$$

where $\overline{\varphi}_{k/(k+1)}$ denotes the significance of $\overline{C}_{j(k)}$ rank compared to the $\overline{C}_{j(k+1)}$ rank.

Step 4. Computation of the optimal fuzzy weights:

$$\frac{\overline{w}_k}{\overline{w}_{k+1}} = \overline{\varphi}_{k/(k+1)} \quad (8)$$

$$\frac{\overline{w}_k}{\overline{w}_{k+2}} = \overline{\varphi}_{k/(k+1)} \otimes \overline{\varphi}_{(k+1)/(k+2)} \quad (9)$$

After that, it should be set the nonlinear model for computation the weights of criteria $(\overline{w}_1, \overline{w}_2, \ldots, \overline{w}_n)^T$.

$$\min \chi$$

$$\begin{cases} \left|\dfrac{\overline{w}_k}{\overline{w}_{k+1}} - \overline{\varphi}_{k/(k+1)}\right| \leq \chi, \forall j, \quad \left|\dfrac{\overline{w}_k}{\overline{w}_{k+2}} - \overline{\varphi}_{k/(k+1)} \otimes \overline{\varphi}_{(k+1)/(k+2)}\right| \leq \chi, \forall j \\ \sum\limits_{j=1}^{n} \overline{w}_j = 1, \quad w^l_j \leq w^m_j \leq w^u_j, \quad w^l_j \geq 0, \forall j, \quad j = 1, 2, \ldots, n \end{cases} \quad (10)$$

where $\overline{w}_j = (w^l_j, w^m_j, w^u_j)$ and $\overline{\varphi}_{k/(k+1)} = (\varphi^l_{k/(k+1)}, \varphi^m_{k/(k+1)}, \varphi^u_{k/(k+1)})$.

3.4. Fuzzy PIPRECIA method

The algorithm of fuzzy PIPRECIA method (Stević et al. 2018) has been presented below:

Step 1. Identification of set of criteria and grouping experts into decision-making team.
Step 2. Evaluation of criteria by each DM by starting from the second criterion.

$$\overline{s^r_j} = \begin{cases} > \overline{1} & if \quad C_j > C_{j-1} \\ = \overline{1} & if \quad C_j = C_{j-1} \\ < \overline{1} & if \quad C_j < C_{j-1} \end{cases} \quad (11)$$

$\overline{s^r_j}$ denotes value of assessment by a DM *r*.

DMs evaluate criteria by applying defined scales in Fig.s 3 and 4.

Step 3. Computation the coefficient $\overline{k_j}$

$$\overline{k_j} = \begin{cases} = \overline{1} & if \quad j = 1 \\ 2 - \overline{s_j} & if \quad j > 1 \end{cases} \quad (12)$$

Step 4. Computation the fuzzy weight $\overline{q_j}$

$$\overline{q_j} = \begin{cases} = \overline{1} & if \quad j = 1 \\ \dfrac{\overline{q_{j-1}}}{\overline{k_j}} & if \quad j > 1 \end{cases} \quad (13)$$

Step 5. Computation the relative weight of the criterion $\overline{w_j}$

$$\overline{w_j} = \frac{\overline{q_j}}{\sum\limits_{j=1}^{n} \overline{q_j}} \quad (14)$$

In the next steps, the inverse version of fuzzy PIPRECIA method has been presented.

Step 6. Assessment using defined scale, starting from a penultimate criterion.

$$\overline{s^r_j}' = \begin{cases} > \overline{1} & if \quad C_j > C_{j+1} \\ = \overline{1} & if \quad C_j = C_{j+1} \\ < \overline{1} & if \quad C_j < C_{j+1} \end{cases} \quad (15)$$

$\overline{s^r_j}'$ denotes value of assessment by DM *r*.

Step 7. Computation the coefficient $\overline{k_j}'$

$$\overline{k_j}' = \begin{cases} = \overline{1} & if \quad j = n \\ 2 - \overline{s_j}' & if \quad j > n \end{cases} \quad (16)$$

n denotes a total number of criteria.

Step 8. Computation the fuzzy weight $\overline{q_j}'$

Linguistic Scale		Fuzzy Number				
			l	m	u	DFV
Almost equal value	Scale 1–2	1	1.000	1.000	1.050	1.008
Slightly more significant		2	1.100	1.150	1.200	1.150
Moderately more significant		3	1.200	1.300	1.350	1.292
More significant		4	1.300	1.450	1.500	1.433
Much more significant		5	1.400	1.600	1.650	1.575
Dominantly more significant		6	1.500	1.750	1.800	1.717
Absolutely more significant		7	1.600	1.900	1.950	1.858

Fig. 3. Scale 1-2.

	Fuzzy Number				Linguistic Scale
	l	m	u	DFV	
Scale 0–1	0.667	1.000	1.000	0.944	weakly less significant
	0.500	0.667	1.000	0.694	moderately less significant
	0.400	0.500	0.667	0.511	less significant
	0.333	0.400	0.500	0.406	really less significant
	0.286	0.333	0.400	0.337	much less significant
	0.250	0.286	0.333	0.288	dominantly less significant
	0.222	0.250	0.286	0.251	absolutely less significant

Fig. 4. Scale 0-1.

$$\overline{q_j}' = \begin{cases} = \overline{1} & if \quad j = n \\ \dfrac{\overline{q_{j+1}'}}{\overline{k_j'}} & if \quad j > n \end{cases} \tag{17}$$

Step 9. Computation the relative weight of the criterion $\overline{w_j}'$

$$\overline{w_j}' = \frac{\overline{q_j}'}{\sum_{j=1}^{n} \overline{q_j}'} \tag{18}$$

Step 10. Defuzzification of the fuzzy values $\overline{w}_j$ and $\overline{w_j}'$

$$\overline{w_j}'' = \frac{1}{2}\left(w_j + w_j{}'\right) \tag{19}$$

Step 11. Computation of Spearman and Pearson correlation coefficients.

4. Case Study

Passenger satisfaction is a significant factor to estimate public transport service quality and performance. This part spot the light on a real-world case study to help policy makers and operators to decide what kind of development they have to take in consider. In this study the city of Mersin in Turkey was selected to conducted and test our integrated model. The public transport system within the city is composed of three types, private buses, private mini buses and public buses.

For our study, we evaluated only public bus transport system which is known as municipality buses by the citizens, because it is actively operated by transportation department in Mersin municipality.

In our study, 14 decision makers and experts participated in the questionnaire survey, the decision makers are official workers in the municipality and the experts has background in the related field.

4.1. Definition of criteria of the urban bus transport supply quality

The following main criteria and sub-criteria (the structure is depicted in Fig. 5) for "Service Quality (C1)" are as follows:

(1) *Approachability (C1.1): is the first main criteria of the UBT system service quality and it intends to the service before beginning the journey which is related to the bus stops and it has three sub-criteria (Directness to stops; Safety of stops and Comfort in stops). The first sub-criteria "Directness to stops (C1.1.1)" refers to the directness to reach the first stop (Saif et al., 2019); the second sub-criteria "Safety of stops (C1.1.2)" means the subjective of commuters' safety pre-journey at bus stops (Cheranchery et al., 2019) and the third sub-criteria is "Comfort in stops (C1.1.3)" refer to the chairs, cooling and heating systems (Miao et al., 2019).*

(2) *Directness (C1.2): it is the second main criteria of the UBT system service quality and it consists of two sub-criteria (The need of transfer and Fit connection). The first related sub-criteria "Need of transfer (C1.2.1)" represents the commuter demand to change service type or not (Duleba and Moslem., 2019); the second related sub-criteria "Fit connection (C1.2.2)" refers to the interaction between urban bus routes or between urban buses and other types of urban transport services (Jin et al., 2019).*

(3) *Reliability (C1.3): it is the third main criteria of the UBT system service quality and it points the quality of confidence deserving,*

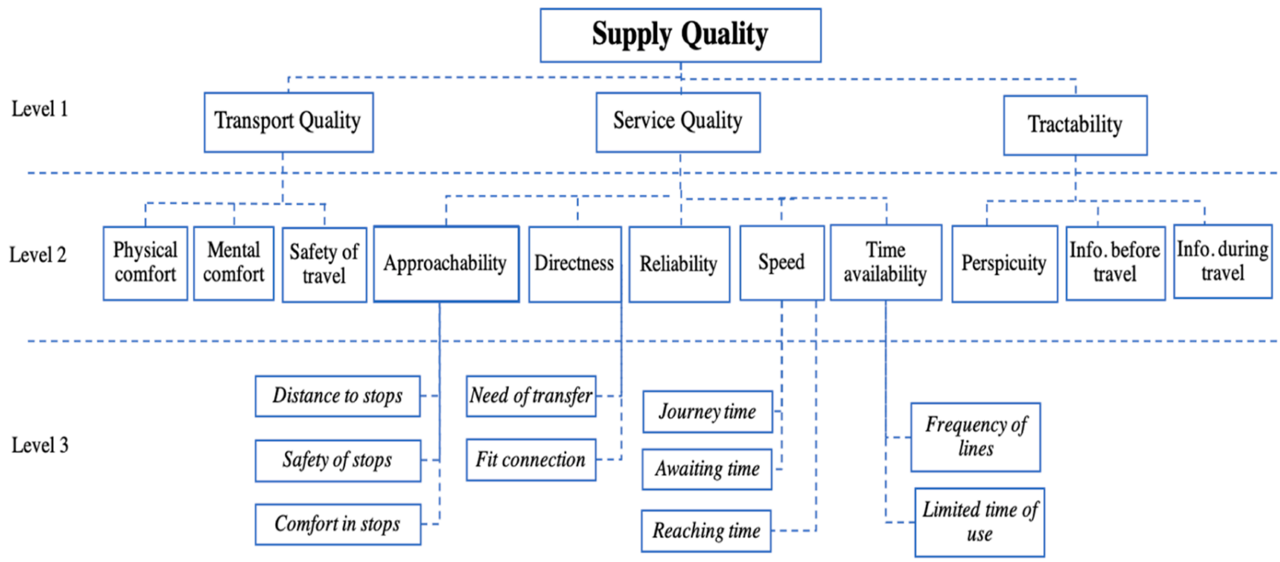

Fig. 5. The hierarchy structure of the supply quality of public bus transport system (Duleba et al., 2012).

through delivering the promised services spotlessly and on the appointed determined time (Soza-Parra et al., 2019).

(4) *Time availability (C1.4): it is the fourth main criteria of the UBT system service quality and it consists of two sub-criteria (The frequency of lines and The limited time of use). The first related sub-criteria "Frequency of lines (C1.4.1)" refer to the number of times that UBT is deployed over a route* (Deng and Yan, 2019); *the second sub-criteria "Limited time of use (C1.4.2)" refers to the time of beginning the UBT service and stalling service during the day* (Scott et al., 2016).

(5) *Speed (C1.5): it is the fifth main criteria of the UBT system service quality and it intends to the speed for the time of whole jouney duration which is related to three sub-criteria (Travel time, Awaiting time and Reaching time). The first sub-criteria "Travel time (C1.5.1)" represent the period of time last by users on-board between first point and arrival point (*Kujala et al., 2018*); the second sub-criteria "Awaiting time (C1.5.2)" refers to the pre-journey waiting time for the service at bus station (*Ingvardson et al., 2018*); the third related sub-criteria "Reaching time (1.5.3)" is the time period that commutes spend to reach the bus stops (*Ingvardson et al., 2018*).*

The following sub-criteria for "Transport Quality (C2)" are as follows:

(1) *Physical comfort (C2.1): it is the seat comfort, crowd, conditioned air.*
(2) *Mental comfort (C2.2): users sense of non-physical comfortability while utilizing the system involving environmental consciousness.*
(3) *Safety of travel (C2.3): represents the feeling of safe, accidents, and security.*

The following sub-criteria for "Tractability" (C3)" are as follows:

(1) *Perspicuity (C3.1): effortless comprehension for schedule and instruction*
(2) *Information before travel (C3.2): exoanse and quality of instruction*
(3) *Information during travel (C3.3): profitable, quantity and quality of instruction "One-way tickets", the fee of a one travel ticket.*

The concrete case, in the considered city, as well in the considered state, there are no competitors of this kind, all alternatives can be considered as attractive. However, expert knowledge is welcome to make a difference between them.

5. Results

In this section has been shown obtained results using IMF SWARA for evaluating public transport supply quality (Fig. 6). The gained results show that the most significant attribute in the first level is the "Traceability" with highest weight score (0.398), followed by the "Transport quality" with weight score (0.334), however, the service quality rank as the last significant attribute with weight score (0.264). In the second level, the "Directness" gained the highest scores and represented the most important factors with respect to the service quality . The "Mental comfort" is the most important factors with respect to transport quality. While the "Perspicuity" is the most important factor with respect to Traceability followed by the "information during the travel".

At the beginning of application of IMF SWARA all criteria from hierarchical structure have been sorted in their own group for each DMs separately. Accordingly, we have formed 14 calculation models for main group of criteria only and in total 112 such models. Example of calculation criteria weights has been shown for DM5 for the main group of criteria contain: transport quality (C1), service quality (C2) and traceability C3. They are ranked as: C3>C1>C2. Applying scale for evaluation, it is determined the *sj*:

$$\overline{s_1} = \left[\frac{2}{7}, \frac{1}{3}, \frac{2}{5}\right]$$

$$\overline{s_2} = \left[\frac{2}{9}, \frac{1}{4}, \frac{2}{7}\right]$$

After that, $\overline{k_j}$ has been computed:

$$\overline{k_3} = [1.000, 1.000, 1.000]$$

$$\overline{k_1} = [1.286, 1.333, 1.400] = \left[1 + \frac{2}{7}, 1 + \frac{1}{3}, 1 + \frac{2}{5}\right]$$

$$\overline{k_2} = [1.222, 1.250, 1.286] = \left[1 + \frac{2}{9}, 1 + \frac{1}{4}, 1 + \frac{2}{7}\right]$$

The elements of matrix $\overline{q_j}$ are obtained:

$$\overline{q_3} = [1.000, 1.000, 1.000]$$

$$\overline{q_1} = \frac{\overline{q_3}}{\overline{k_1}} = \frac{1.000}{1.400}, \frac{1.000}{1.333}, \frac{1.000}{1.286} = [0.714, 0.750, 0.778]$$

$$\overline{q_2} = \frac{\overline{q_1}}{\overline{k_2}} = \frac{0.714}{1.286}, \frac{0.750}{1.250}, \frac{0.778}{1.222} = [0.556, 0.600, 0.636]$$

The final fuzzy criterion weights $\overline{w_j}$ are calculated:

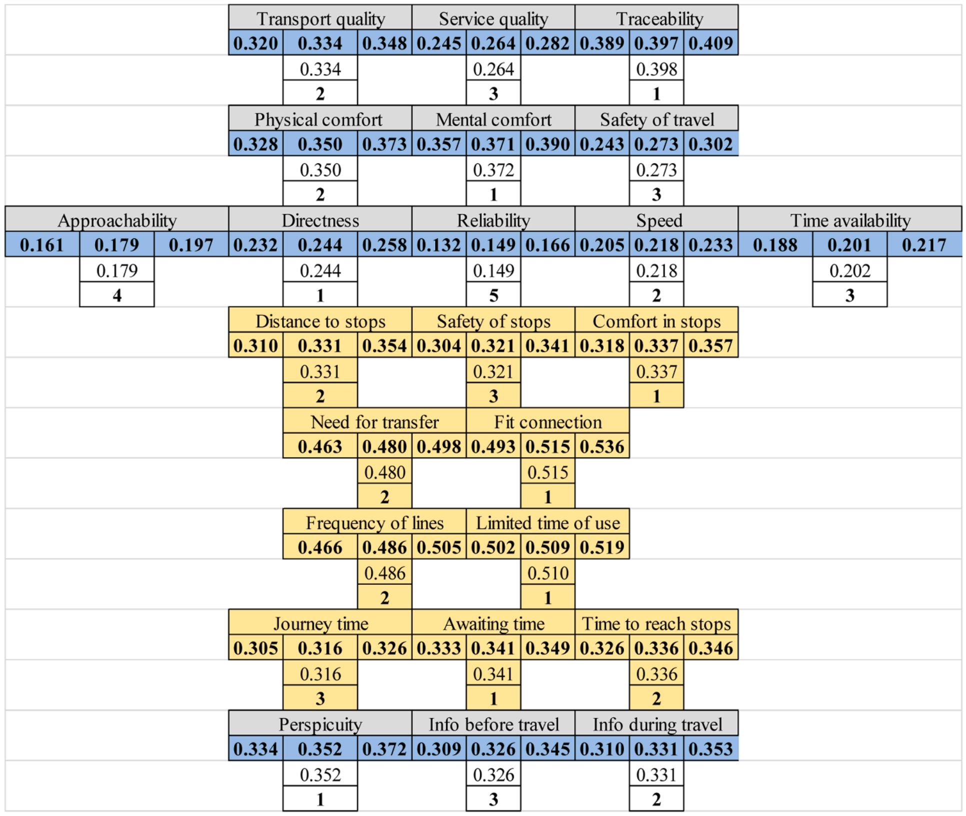

Fig. 6. . Obtained results using IMF SWARA for evaluating public transport supply quality

$$\overline{w_3} = \frac{\overline{q_3}}{\sum_{j=1}^{3} \overline{q_j}} = \frac{1.000}{2.414}, \frac{1.000}{2.350}, \frac{1.000}{2.270} = [0.414, 0.426, 0.441]$$

$$\overline{w_1} = \frac{\overline{q_1}}{\sum_{j=1}^{3} \overline{q_j}} = \frac{0.714}{2.414}, \frac{0.750}{2.350}, \frac{0.778}{2.270} = [0.296, 0.319, 0.343]$$

$$\overline{w_2} = \frac{\overline{q_2}}{\sum_{j=1}^{3} \overline{q_j}} = \frac{0.556}{2.414}, \frac{0.600}{2.350}, \frac{0.636}{2.270} = [0.230, 0.255, 0.280]$$

The other fuzzy weights are obtained in the same way.

Then, the fuzzy Bonferroni Mean operator was applied to obtain the initial fuzzy matrix. An example of calculation for the main group for C1 is as follows:

$$BM^{p=1,q=1}\left\{ \begin{array}{l} (0.250, 0.250, 0.250), (0.364, 0.368, 0.375), (0.192, 0.229, 0.266), \ldots, \\ (0.429, 0.446, 0.471), (0.333, 0.333, .0333) \end{array} \right\} =$$

$$\left\{ \begin{array}{l} \varpi^{l}_{C_{1(1)}} = \left(\frac{1}{14(14-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{14} \varpi^{lp}_{C_{1(1)}i} \varpi^{lq}_{C_{1(1)}j} \right)^{\frac{1}{1+1}} = \left(0.0055\left(0.250^{1} \cdot 0.364^{1} + 0.250^{1} \cdot 0.192^{1} + \ldots + 0.250^{1} \cdot 0.333^{1}\right)\right)^{\frac{1}{1+1}} = 0.320 \\ \varpi^{m}_{C_{1(1)}} = \left(\frac{1}{14(14-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{14} \varpi^{mp}_{C_{1(1)}i} \varpi^{mq}_{C_{1(1)}j} \right)^{\frac{1}{1+1}} = \left(0.0055\left(0.250^{1} \cdot 0.368^{1} + 0.250^{1} \cdot 0.229^{1} + \ldots + 0.250^{1} \cdot 0.333^{1}\right)\right)^{\frac{1}{1+1}} = 0.334 \\ \varpi^{u}_{C_{1(1)}} = \left(\frac{1}{14(14-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{14} \varpi^{up}_{C_{1(1)}i} \varpi^{uq}_{C_{1(1)}j} \right)^{\frac{1}{1+1}} = \left(0.0055\left(0.250^{1} \cdot 0.375^{1} + 0.250^{1} \cdot 0.226^{1} + .. + 0.250^{1} \cdot 0.333^{1}\right)\right)^{\frac{1}{1+1}} = 0.348 \end{array} \right.$$

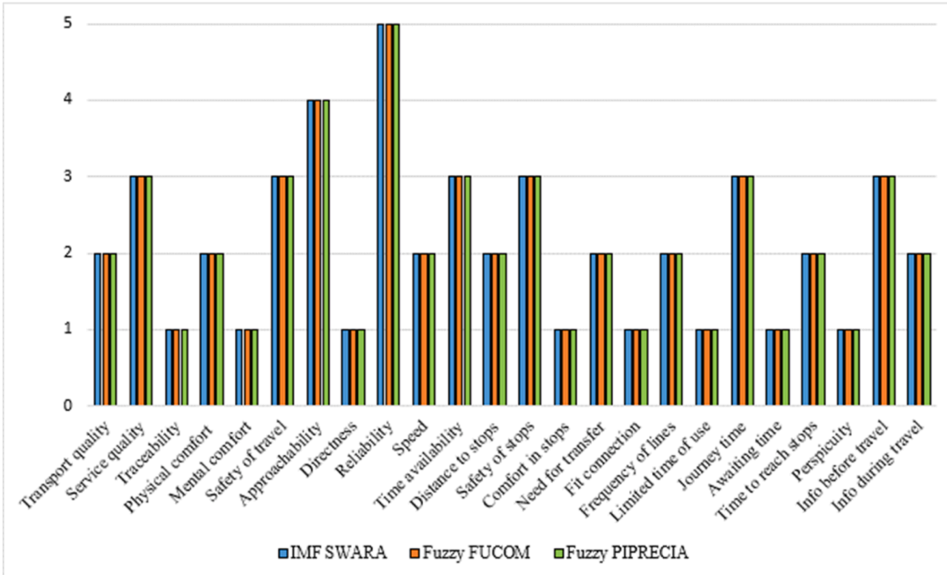

Fig. 7. Ranking of criteria in comparative anylsis

Transport Quality			Service Quality			Tractability		
0,32	0,334	0,348	0,245	0,264	0,282	0,389	0,397	0,409
0,271	0,337	0,402	0,21	0,269	0,362	0,304	0,394	0,523
PCC	0,732							

Physical comfort			Mental comfort			Safety of travel		
0,328	0,35	0,373	0,357	0,371	0,39	0,243	0,273	0,302
0,262	0,339	0,388	0,317	0,368	0,431	0,249	0,293	0,389
PCC	0,71							

Approachability			Directness			Reliability			Speed			Time availability		
0,161	0,179	0,197	0,232	0,244	0,258	0,132	0,149	0,166	0,205	0,218	0,233	0,188	0,201	0,217
0,122	0,179	0,269	0,17	0,262	0,381	0,109	0,154	0,219	0,156	0,225	0,314	0,124	0,18	0,286
PCC	0,748													

Distance to stops			Safety of stops			Comfort in stops		
0,31	0,331	0,354	0,304	0,321	0,341	0,318	0,337	0,357
0,264	0,32	0,375	0,217	0,276	0,367	0,315	0,404	0,53
PCC	0,897							

Need for transfer			Fit connection		
0,463	0,48	0,498	0,493	0,515	0,536
0,431	0,5	0,536	0,494	0,5	0,549
PCC	0,813				

Frequency of lines			Limited time of use		
0,466	0,486	0,505	0,502	0,509	0,519
0,41	0,464	0,55	0,494	0,536	0,563
PCC	0,966				

Journey time			Awaiting time			Time to reach stops		
0,305	0,316	0,326	0,333	0,341	0,349	0,326	0,336	0,346
0,25	0,285	0,367	0,32	0,357	0,41	0,28	0,357	0,4
PCC	0,895							

Perspicuity			Info before travel			Info during travel		
0,334	0,352	0,372	0,309	0,326	0,345	0,31	0,331	0,353
0,325	0,399	0,464	0,238	0,3	0,36	0,277	0,3	0,369
PCC	0,975							

Fig. 8. The The PCC results between IMF SWARA and Fuzzy FPIPRECIA

The same procedure was repeated for each criterion separately.

5.1. Comparative analysis

In this stage, a comparison for the criteria method was performed. Two other popular methods namely Fuzzy FUCOM and Fuzzy PIPRECIA has been applied. The comparative analysis for the criteria method is shown in Fig. 7.

It should be noted no any changes in criteria ranking, which can be consequence of small number of comparison in each group of criteria (2-5).

Moreover, we have checked correlation between weights obtained using IMF SWARA and Fuzzy PIPRECIA and IMF SWARA with Fuzzy FUCOM. These correlations have been checked by Pearson's coefficient of correlation (PCC) (Adler and Parmryd, 2007).

The PCC results between IMF SWARA and Fuzzy FPIPRECIA were acceptable and show the relaiblity of the obtained resutls is presented in the Fig. 8 (where IMF SWARA values are in blue color and Fuzzy FPIPRECIA values are in green color):

The PCC results between IMF SWARA and Fuzzy FUCOM were acceptable and show the relaiblity of the obtained resutls is presented in Fig. 9 (where IMF SWARA values are in blue color and Fuzzy FUCOM values are in orange color):

6. Discussion and Conclusions

The questionnaire survey was estimated by 14 DMs and transport planners in the municipality, they evaluated the pairwise comparison matrices considering improving the public bus transport system to provide more efficient and sustainable service. The main structure of the problem took in consider all related factors to the supply quality of the public bus transport system in Mersin city, which is actively operated by the transportation department at the municipality. Based on the conducted model, the adopted results illustrated that the most significant attribute in the system is the "Tractability" with highest weight score (0.398), this shows the demand for understanding the schedule and instruction, also getting a clear information not only before the journey, but also during the journey time. The second most significant attribute in the first level was the "Transport quality" with weight score (0.334), its importance degree is almost close to the "Tractability", since the security, comfort and environmental consciousness is critical demand to enhance the system and satisfy the users group. The least significant attribute is the "Service quality" with weight score of (0.264), which represents the importance degree of the approachability, reliability, speed and time availability.

Taking in consider the "Transport quality" branch in level 2, the "Mental comfort" is the most important criteria with weight score (0.372), followed by "Physical comfort" and "Safety of travel" with weight scores (0.350) and (0.273). The gained results from the "Service

Transport Quality			Service Quality			Tractability		
0,32	0,334	0,348	0,245	0,264	0,282	0,389	0,397	0,409
0,327	0,327	0,327	0,286	0,313	0,342	0,343	0,36	0,376
PCC	0,852							

	Physical comfort			Mental comfort			Safety of travel		
	0,328	0,35	0,373	0,357	0,371	0,39	0,243	0,273	0,302
	0,337	0,337	0,337	0,344	0,354	0,36	0,296	0,31	0,322
PCC	PCC	0,962							

Approachability			Directness			Reliability			Speed			Time availability		
0,161	0,179	0,197	0,232	0,244	0,258	0,132	0,149	0,166	0,205	0,218	0,233	0,188	0,201	0,217
0,156	0,198	0,198	0,243	0,271	0,271	0,137	0,166	0,166	0,17	0,198	0,198	0,16	0,194	0,194
PCC	0,867													

Distance to stops			Safety of stops			Comfort in stops		
0,31	0,331	0,354	0,304	0,321	0,341	0,318	0,337	0,357
0,328	0,328	0,328	0,297	0,314	0,331	0,345	0,358	0,371
PCC	0,647							

Need for transfer			Fit connection		
0,463	0,48	0,498	0,493	0,515	0,536
0,47	0,49	0,5	0,5	0,52	0,53
PCC	0,987				

Frequency of lines			Limited time of use		
0,466	0,486	0,505	0,502	0,509	0,519
0,463	0,481	0,495	0,497	0,503	0,52
PCC	0,983				

Journey time			Awaiting time			Time to reach stops		
0,305	0,316	0,326	0,333	0,341	0,349	0,326	0,336	0,346
0,283	0,308	0,336	0,354	0,37	0,386	0,322	0,322	0,322
PCC	0,782							

Perspicuity			Info before travel			Info during travel		
0,334	0,352	0,372	0,309	0,326	0,345	0,31	0,331	0,353
0,362	0,379	0,395	0,259	0,291	0,329	0,329	0,329	0,329
PCC	0,77							

Fig. 9. The The PCC results between IMF SWARA and Fuzzy FUCOM

quality" branch in level 2 shows that the "Directness" attribute is the most significant one with the highest weight score (0.244) followed by the "Speed" and "Time availability", however, the least significant attribute is the "Reliability" followed by the "Approachability". In the same level (level 2), the most important attribute related to the "Tractability" is "Perspicuity" with weight score (0.352), followed by the "information during travel" and "information before travel". In level 3, taking the in consider the "Approachability" branch the "Comfort in stops" detected as the most critical attribute with weight score (0.337), followed by "distance to stops", however, the "Safety of stops" detected as less critical criterion with (0.321) weight score. At same level, with considering the "Time availability" branch, the results show the "Awaiting time" as the most important criteria, followed by the "Time to reach stops" and "Journey time". Subsequently, the "Fit connection" is more important than "Need for transfer" considering the "Directness" branch. While the "Limited time of use" is more important than the "Frequency of lines" considering "Speed" branch. The main objective of enhancing the supply quality of public transport system is to pull down private vehicle trips and thus traffic which interns affect positively on the environment and on reducing road transport related CO2 emissions, since the public transport system is a widely promoted mode by planners and scholars that take into consideration reducing traffic in the urban environment of a city.

Practical problems, and especially quality assessment, very often need the application of precise MCDM models which treat uncertainty in adequate way. For that reason, we have proposed using of IMF SWARA method for improving the service quality of the public transport system because using fuzzy set theory provides adequate treatment of uncertainty. The advantage of the proposed methodology is the integration IMF SWARA method in Fuzzy Bonferroni operator in order to obtain better and more precise results. This study proposed group decision-making in the transport sector which is preferable for decision analysis in complex systems.

One of the limitations of this study is the fact that we didn't include users in the calculation model, but data has been collected and one of the future directions is to create a model based on their opinion. Also, one of the stages for continue of this research should be to use a rough set MCDM model which is a good option for group decision-making.

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Declaration of Competing Interest

The authors declare no conflict of interest.

Data Availability

Data will be made available on request.

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