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Sustainable Urban Transport Planning Considering Different Stakeholder Groups by an Interval-AHP Decision Support Model

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Abstract: Sustainable urban transport requires smart and environmentally-friendly technical solutions. It also needs to meet the demands of different user groups, including current and potential future users, in order to avoid opposition of the citizens and to support sustainable development decisions. While these requirements are well-known, conducting full surveys of user needs and preferences are tedious and costly, and the interests of different user groups may be contradictory. We therefore developed a methodology based on the prevalent Analytic Hierarchy Process (AHP), which is capable of dealing with the inconsistencies and uncertainties of users' responses by applying an Interval Analytic Hierarchy Process (IAHP) through comparing the results of passengers to reference stakeholder groups. For a case study in Mersin, a coastal city in southern Turkey with 1.7 Million inhabitants, three groups were surveyed with questionnaires: 40 users of the public transport system, 40 non-users, and 17 experts. Based on interval pairwise comparison matrices, consisting of whole judgments of all groups, the IAHP methodology could attain a consensual preference ranking for a future public transportation system between the three groups. A sensitivity analysis revealed that the factor ranking was very stable.

Keywords: sustainable transport policy; multi-criteria decision making (MCDM); interval calculus; supply quality; stakeholder engagement

1. Introduction

It is generally well-known in environmental sciences that, globally, cities are responsible for more than 70% of total greenhouse gas (GHG) emissions [1] and this proportion is constantly rising. Primarily transportation and waste projects are required to reduce urban GHG emissions [2] by improving the efficiency of these sectors in terms of causing lower pollution. For urban transport, an evident step forward could be to motivate citizens to shift from private vehicle use to public transportation. However, the tendencies are contrary, especially for the cities of developing countries [3] in which the inadequate public transport network has caused people to turn to private cars. The scientific literature has listed some influencing factors that might help in turning this environmentally threatening trend around, e.g., through reduced transit times and reduced distance from home to transit stations [4], increased public vehicle accessibility [5], decreased travel time [3] or improved non-general elements of the supply quality, such as the perspicuity of the timetables [6]. Thus, the projects endeavoring to increase public transport utilization must focus on some of the crucial factors of the particular public transport system and allocate financial resources for the development of the most preferred elements of the supply quality.

It is widely acknowledged that creating a sustainable urban transport plan goes beyond technical transportation issues and timetables and should consider financial, social and environmental factors [7]. Ioppolo et al. [7] identified security, accessibility, health impacts and other environmental and socio-economic indicators as important for creating a strategic sustainability plan for an Italian area and found that resettlement, housing and land use mostly influence the creation of urban transport planning [8]. For the case of Mersin, however, the primal objective of the municipality was to acquire citizens' knowledge and preferences on the operating bus system and comparing the results to expert opinions. Thus, for the questionnaire creation direct economic factors (such as fares) were omitted in the decision structure to avoid non-realistic or exaggerated preferences from potential passengers. Environmental issues were neither explicitly included in the questionnaire but the element "mental comfort" is indirectly related. The evaluators were informed that mental comfort includes the feeling of protecting the environment by choosing public transport instead of a private car and that assigning a high value means that this is an important argument for the evaluator. The key elements of public transport services are most commonly determined by the urban transport operator, often with the participation of representatives of the municipality [9]. Most likely, a top-down decision has been made not only in emerging countries but also in developed countries [10], and this decision does not necessarily reflect public opinion. Thus, the sustainability of this decision cannot be ascertained; perhaps the public act in a contrary way if preferences of the society and citizens are not considered in a transport development decision and the original objective, the shift to public transport, cannot be reached [11].

1.1. Public Involvement in Urban Transport Development

Public engagement in urban development has become a significant issue in recent years, to the extent that a growing number of examples can be found in the legislation to provide citizens with the opportunity to influence decisions that affect their lives (U.S. Department of Transportation, 2015). In the United States, a law called Safe, Accountable, Flexible, Efficient Transportation Equity Act: a Legacy for Users (SAFETEA-LU, 2015) was created in order to foment considering users' needs and preferences in development decisions. Another example is the requirement of a Sustainable Urban Mobility Plan (SUMP) in which public aspects have to be mapped before creating a transport development plan for European Union Countries. Moreover, the scientific literature also advises citizen involvement: urban planning theory suggests that public engagement should be implemented to help move forward [12]. Many researchers concluded that the achievements of public participation rely upon the extent to which the public is permitted to be involved [13]. Some authors claim that public participation is inevitable, not only for sustainable planning but also for the implementation phase, for instance by formulating citizen advisory committees [14].

However, users are not the only stakeholders of an urban transport development plan and implementation. Soma et al. [15] distinguished between government based and stakeholder based participation, while Duleba et al. [6] separated three stakeholder groups related to a public transport system development decision: users, governmental officials and transport company managers. Evidently, the motivations of these groups differ; passengers require the highest possible service quality without considering the cost aspects that are very important for the operator company and for the government. The representatives of the municipality endeavor to raise public satisfaction while the public transport company focuses on the technical issues and operational efficiency. In many emerging countries, the collaboration between the local government and the local transport operator company is typically tighter or less regulated so that the motivation of these two groups can be considered as almost identical. Thus for Mersin city, a consolidated group of "decision makers" has been formed.

Cities around the world are faced with population growth and expeditious suburbanization, and the implementation of public transportation is a means to reduce traffic, environmental and public health problems [16]. The gap between the passengers' and the decision makers' image on the level of service quality of the public transportation and the necessary implementations is huge in many cases.

Public participation in decision-making implies a possibility for the public to impact the improvement of regulations and laws which influence them and those citizens should have the opportunity to influence decisions that affect their lives (U.S. Department of Transportation, 2015). Garrido et al. [17] have ranked the most important factors of service quality related to public transport while considering the passengers' point of view. Nassereddine and Eskandari [18] conducted a passenger survey in Tehran on future improvements for service quality in different transportation modes. On the other hand, Duleba [19] considered the public and decision maker point of view to evaluate not only the service quality but also the transport quality to enumerate the supply quality factors of a public bus system.

Including citizens in decisions that relate to their lives will also create a kind of motivation, especially when involving them in public transportation decisions. For example, including citizens in public bus transportation decisions can help to improve bus comfort and thus attract more passengers [16,20,21].

1.2. Literature Review on MCDM for Transportation and Consultation Efforts

Multi-Actor, Multi-Criteria Decision Analysis (MAMCA) supports transport project decisions through stakeholder participation [22,23]. MAMCA applies different criteria to stakeholder groups, determined a priori based on their objectives related to the main goal of the decision. We identified MAMCA to be suitable for the Mersin study because the aim of the local government was to gain information about the perception different groups of the operating bus system's supply quality as well as to coordinate and mediate the different views. Consequently, each group evaluated the same criteria structure and the results were compared and synthesized. Thus, a methodological procedure had to be created which is capable of dealing with the complexity of the criteria, handling separately the decision maker groups and last but not least synthesizing the views through a computational approach [24]. Because of the complexity of public transportation development decisions due to the various criteria to be considered and a feasible final decision to be made, multi-criteria methods (MCDM) seemed worth studying [25]. MCDM methodologies have been used widely in transport projects [26] and one of the most popular MCDM approaches that support decision makers' decisions is the AHP approach [27]. As the AHP can deal with typical problems of complex scenarios, it is appropriate for decision-making problems that have to consider multiple criteria and multiple stakeholder groups [28]. Compared to other MCDM techniques (e.g., PROMETHEE, ELECTRE, TOPSIS) AHP bears the advantage that it provides the evaluators with a clear hierarchical decision structure which is an asset when involving non-expert participants as in the case of Mersin. In addition, the built-in consistency check is particularly useful when involving layman evaluators. The pros and cons of this approach regarding public transport options are comprehensively described by [24,28]. AHP is not a statistical technique; it is a dynamic analysis that reflects the real perception of the problems by the involved stakeholders based on a dynamic questionnaire survey [29]. There have been several applications of this method in the field of transportation. Boujelbene and Derbel [30] worked on tracing the weaknesses of the public transport performance in different cities of Tunisia to contrive solutions and improve them by applying AHP. They developed an evaluation criterion to compare different operators working in similar conditions to find the best performing public transport operator. Vaidya [31] applied the AHP approach to evaluate the relative performance of 26 public urban transportation organizations in India using 19 criteria clustered as operational, financial, and accident-based, to help decision makers achieve better results. Although the AHP is used for several multi-criteria problems, such as improving the quality of public transportation, the technique is not satisfactory for all types of studies and can suffer from some inability e.g., produces unreliable results [32]. The common limitation of the AHP is that there can be a number of groups involved in a problem and using crisp numbers to express their opinions in the pairwise comparison matrices is difficult [33]. The decision makers or different groups of decision makers are sometimes not actually fully aware of the nature of the criteria or they have their own preferences with respect to compare the criteria [34]. In addition, not all groups or members of a group will agree on a value for a specific criterion, and they will rarely attain agreement on a full set of weightings for decision-making [35]. The difficulties of using AHP are magnified when one considers a multi-criteria problem which is fully participatory.

In such participatory situations, it is not clear whether AHP can appropriately deal with a situation where decision makers are involved in various groups all dealing with the problem that is of interest to them [36,37]. The criteria ranking can be altered by even just a small change in the criteria weighting process. In order to deal with these issues, many studies have aimed at reducing the amount of inherent uncertainty associated with the AHP method. There are some studies that have suggested the use of sensitivity and uncertainty analyses and integration of the AHP with statistical approaches such as the Monte Carlo simulation [38,39]. The fuzzy-AHP is based on different membership functions that are considered to be an effective and flexible technique in some cases [40]. In Tunisia and Tanzania a combined model of fuzzy entropy and fuzzy TOPSIS had been applied to enumerate the quality of transport service of Dar es Salaam City [41]. Interval calculus has also been integrated with the pairwise comparison matrices of the AHP to increase the flexibility of the results by using a wide range of questionnaires and to improve the reliability of the weighting results [42]. This integration is helpful for solving problems that require different types of experts and questionnaires. Some difficulties result from differences in judgment between different experts concerning the same issues. The interval calculus is also more practical when experts are not confident about the Eigen values of AHP for making a complex decision [43].

In this paper, the AHP approach has been used to evaluate citizen demands for public bus transportation in Mersin city, Turkey. Moreover, the collected data has been analyzed using an interval calculus of AHP (IAHP) to attain the overall weights from three different groups, namely passengers, non-passengers and decision makers.

2. Methodology

2.1. Workflow for MCDA Applied to Public Transport Supply

This study exerts both the advantages of the traditional AHP method and considers the uncertainty risk in a passenger survey by applying the Interval Analytic Hierarchy Process (IAHP) through comparing the results to two reference groups.

The first step was constructing questionnaires based on a created supply quality element hierarchy of the public bus transport system for the target evaluator groups. Although the same questionnaire was used, obviously the different groups were surveyed for different reasons. The passenger group was selected to evaluate what might increase their satisfaction with regard to the public bus transport system, the non-passengers group was selected in order to ascertain what might attract them to start utilizing the public bus transport as opposed to their private cars, while the decision maker group was selected to identify the gap between them and the public and to attain technical expertise. In the second step, the pairwise comparison (PC) questionnaire was structured, and the data was collected. Then, the consistency of the matrices was checked as suggested by [44], followed by the application of the geometric mean, derivation of the weight vectors and calculation of the final scores. The final step was the sensitivity analysis in order to check the stability of the scores.

The analyzed problem is hierarchically structured and the AHP methodology applied considered three requirements:

- A consistency check is required (passengers and non-passengers are evaluators);
- The ranking of factors is both ordinal and cardinal;
- In the final decision, not only is the ranking itself important but also the scores assigned to each factor.

Figure 1 exhibits the created hierarchy for the public bus transport in Mersin. First, the supply quality has been divided into three general elements: transport quality refers to the issues specifically related to the journey on the vehicle, tractability to the provided information that users get and service quality to other related conditions (for more details please see [6]). Then these items have been specified in more detail on the second level and further more on the third. A strong argument for applying this hierarchy was the successful application of this supply quality approach in Japan in 2012 [6]. Some explanation of the decision elements might be necessary for the readers for better understanding. As pointed out previously, "Mental comfort" includes the mental well-being on the vehicle also regarding environmental considerations. Security requirements during the journey are included in the "Safety of travel" item. "Perspicuity" means the understandability of the timetables, while "Approachability" refers for the initial phase of the journey proceeding to bus stops. "Directness" is the general item for the origin-destination aspect of the journey: how many times does a user have to change vehicles to reach his/her destination and how these lines are linked to each other. "Reliability" refers to the delays and "Limited time of use" is expressing the departure time of the first line in the morning and the last in the evening. As stated before, transport fares are not included in the model, so just supply quality issues are investigated. All participants of the survey agreed in using this structure and an instructor explained the questionable items during the evaluation process.

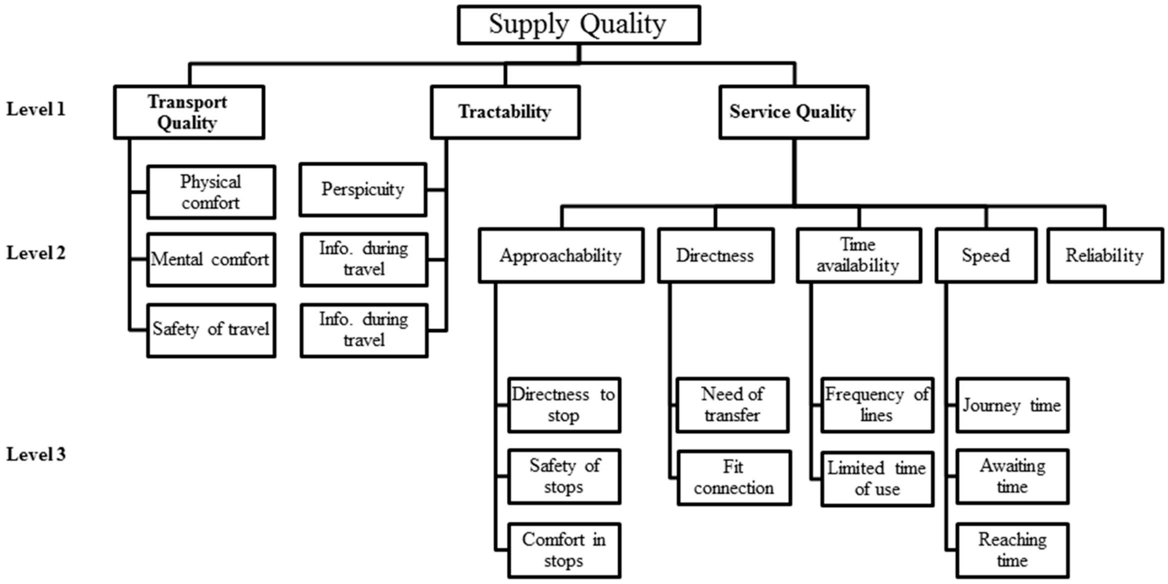

Figure 1. The hierarchical structure of the public bus transport supply quality.

Another characteristic of the AHP approach is the capability of examining the different opinions of various stakeholder groups of public transport: the government as a maintainer, organization as the administrator and travelers as clients. Their conflicting views regarding the key-purposes of a specific framework can be the reason for wrong choices regarding public transport implementation [45]. The different viewpoints of passengers, non-passengers and decision makers justify the use of different evaluator groups.

PCs had to be completed by the survey participants for all elements of the model while considering the hierarchy levels. The number of participants is not subject to statistical representativity because the MCDM provides a deeper insight based on PCs than simple statistical survey and smaller sample sizes can be satisfactory. When investigating the phenomenon "Wisdom of the crowds" Solomon [46] diagnozed representativeness from roughly 20 participants because even this number of people can filter out the extreme opinions. In our sample, the 40 randomly selected people for both citizen groups can be considered as sufficient. Moreover, the sensitivity analysis did not show sensitivity for the sample size.

The following questions were asked at the 1st level: 'Compare the importance of improvement for the service quality and transport quality element. Compare the importance of improvement for the service quality and tractability elements. Compare the importance of improvement for the transport quality and tractability elements'. For the 2nd and 3rd level the same comparison structure was constructed.

2.2. Conventional AHP

The AHP utilizes the special characteristics of pairwise comparison matrices (PCM). A theoretical PCM is quadratic, reciprocal and consistent.

The matrix $\boldsymbol{A}$ is considered consistent if all of its elements are positive, transitive and reciprocal as shown in (1) and (2):

$$a_{ik} = a_{ij} \cdot a_{jk} \tag{1}$$

$$a_{ij} = 1/a_{ji} \tag{2}$$

The dominant eigenvector of such PCM is trivial to be determined by using Saaty's eigenvector method.

If $\boldsymbol{A}$ is a consistent matrix, $\boldsymbol{A} \cdot w = \lambda_{max} w$. Then the eigenvector w can be calculated as $(\boldsymbol{A} - \lambda_{max}\boldsymbol{I})w = 0$, where is the maximum eigenvalue of the matrix $\boldsymbol{A}$.

Although in the AHP, decision makers most likely do not evaluate PCMs consistently (for the evaluation, the Saaty scale is recommended, see Table 1), the eigenvector method can be used if a consistency check has been carried out for the evaluations.

Table 1. Judgment scale of relative importance for pairwise comparisons (PCs) (Saaty's 1–9 scale).

Numerical Values	Verbal Scale	Explanation
1	Equal importance of both elements	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgment favour one element over another
5	Strong importance of one element over another	An element is strongly favoured
7	Very strong importance of one element over another	An element is very strongly dominant
9	Extreme importance of one element over another	An element is favoured by at least an order of magnitude
2, 4, 6, 8	Intermediate values	Used to compromise between two judgments

Consequently, during the AHP process, the consistency of answers must be examined by Saaty's Consistency Index (*CI*) and Consistency Ratio (*CR*) [47]:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3}$$

where *CI* is the consistency index, λ_{max} is the maximum eigenvalue of the PCM and n is the number of rows in the matrix. *CR* can be determined by

$$CR = \frac{CI}{RI} \tag{4}$$

Saaty provides the calculated *RI* values for matrices of different sizes as shown in Table 2.

Table 2. Consistency indices for a randomly generated matrix.

n	2	3	4	5	6	7	8	9
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Where RI is the random consistency index. In this study, a standard CR threshold value of 0.10 was applied ($CR < 0.1$), in the survey, all PCM-s resulted as acceptable from inconsistency point of view.

Since the survey of Mersin involved several evaluators, the most accepted aggregation process of AHP has been applied: the geometric mean of the respective evaluator scores taken from individual matrices for creating aggregated matrices of these values. If "h" evaluators exist in the procedure, then

$$A = \left[\sqrt[h]{\prod_{k=1}^{h} a_{ijk}} \right] i, j = 1, \ldots, n. \tag{5}$$

Formula (5) refers to the scores of the k-th evaluator. After producing the aggregated matrices, deriving weight vector scores is the next step in the procedure. As consistency has been deemed acceptable, the eigenvector method can be applied as

$$w_{A_i} = \frac{w_j}{w} \frac{w_{ij}}{\sum_{k=1}^{n} w_{ik}} = \left(\frac{w_j}{w} \frac{1}{\sum_{k=1}^{n} w_{ik}} \right) w_{ij} \tag{6}$$

where $j = 1, \ldots, m$ and $w = \sum_{i=1}^{m} w_j$; $wj > 0$ ($j = 1, \ldots, m$) represents the related weight coordinate from the previous level; $w_{ij} > 0$ ($i = 1, \ldots, n$) is the eigenvector computed from the matrix in the current level, w_{Ai} ($i = 1, \ldots, n$) is the calculated weight score of current level's elements. Sensitivity analysis enables understanding the effects of changes in the main criteria on the sub criteria ranking and helps decision makers to check the robustness throughout the process.

The consistency ratio (CR) was less than 0.1 for all experiential PCM; therefore the AHP analysis could be completed.

2.3. Interval-AHP

In this study, we aim to attain a comprehensive understanding of the satisfaction of different groups with regard to the public transportation system. Therefore, we calculated the level of satisfaction based on the opinions of three different groups. The complexity of the public transportation in any city, and in Mersin city as our case study, can be defined as the diversity of different groups who were considered to be stakeholders of the system. The degree of diversity in any problem is illustrated by the number of emergent properties [48]. In our case, using the comments of these different groups resulted in diverse values in the pairwise comparison matrices of the AHP. Thus, it is difficult to obtain a reasonable CR and reliable weights [34]. Even if we consider only one group, the conventional AHP has some limitations to covering all opinions regarding the problem. For example, Goodwin and Wright [49] clearly referred to the haziness of the questions making up the pairwise comparison matrices. The questions posed by researchers relate only to the values associated with the considered factor, with no further information about the scales on which the factors are compared [50]. The haziness resulting from the degree of subjectivity associated with this method can lead to different interpretations by different respondents [51]. To overcome these concerns, we use interval matrices for pairwise comparisons in the AHP technique. In this case, pairwise comparison matrices were carried out using numerical intervals. The low values of comparisons were considered as the lower bound, and the higher values were considered as the upper bound of the interval. Let a and b be those values with $a \leq b$. The set $x = [a, b] = \{ y \in \mathbb{R} : a \leq y \leq b \}$ is considered as our interval. The set of all our intervals is denoted as $\mathbb{IR}$. The binary operations like multiplication and division can easily be defined on $\mathbb{IR}$. The comparison matrix of $A = \left(r_{ij}\right)_{n\times n} \subset X \times X$ as (7):

$$\begin{cases} r_{ij} \times r_{ji} = 1, \forall i,j = 1,2,\ldots,n \\ r_{ii} = 1, \\ r_{ij} \geq 0 \end{cases} . \tag{7}$$

is consistent if the following (8) transitivity is satisfied [29]:

$$r_{ij} = \frac{r_{ik}}{r_{jk}} \forall i,j,k = 1,2,\ldots,n \tag{8}$$

If using an interval of $x = \left[a_{ij}, b_{ij}\right]$, x clarifies that the factor x_i is between a_{ij} and b_{ij} times as preferable to the factor x_j, then the interval comparison matrix is defined as (9):

$$A = \begin{bmatrix} 1 & [a_{12},b_{12}] & \ldots & [a_{1i},b_{1i}] & \ldots & [a_{1j},b_{1j}] & \ldots & [a_{1n},b_{1n}] \\ [a_{21},b_{21}] & 1 & \ldots & [a_{2i},b_{2i}] & \ldots & [a_{2j},b_{2j}] & \ldots & [a_{2n},b_{2n}] \\ \ldots & \ldots & 1 & \ldots & \ldots & \ldots & \ldots & \ldots \\ [a_{i1},b_{i1}] & [a_{i2},b_{i2}] & \ldots & 1 & \ldots & [a_{ij},b_{ij}] & \ldots & [a_{in},b_{in}] \\ \ldots & \ldots & \ldots & \ldots & 1 & \ldots & \ldots & \ldots \\ [a_{j1},b_{j1}] & [a_{j2},b_{j2}] & \ldots & [a_{ji},b_{ji}] & \ldots & 1 & \ldots & [a_{jn},b_{jn}] \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & 1 & \ldots \\ [a_{n1},b_{n1}] & [a_{n2},b_{n2}] & \ldots & [a_{ni},b_{ni}] & \ldots & [a_{nj},b_{nj}] & \ldots & 1 \end{bmatrix} \tag{9}$$

$$a_{ij} \leq b_{ij},\ \forall\ i,j = 1,2,\ldots,n \ \text{ and } \ a_{ij} \geq 0\ ,\ b_{ij} \geq 0,\ \forall\ i,j = 1,2,\ldots,n$$

This matrix is a reciprocal and definite comparison matrix as defined in (10):

$$a_{ij} = \frac{1}{b_{ji}},\ \ b_{ij} = \frac{1}{a_{ji}},\ \forall\ i,j = 1,2,\ldots,n \tag{10}$$

For evaluation of the *CR* of this matrix and for further calculations of the AHP, matrix $\boldsymbol{A}$ should be a reciprocal matrix. In this case, we can easily separate it into two matrices, $P = \left(p_{ij}\right)_{n\times n}$ and $Q = \left(q_{ij}\right)_{n\times n}$ such that

$$p_{ij} = \begin{cases} b_{ij} & i < j \\ 1 & i = j \\ a_{ij} & i > j \end{cases} \quad , \quad q_{ij} = \begin{cases} a_{ij} & i < j \\ 1 & i = j \\ b_{ij} & i > j \end{cases} \tag{11}$$

We also define another matrix $D(\alpha)$ as

$$D(\alpha) = \left(d_{ij}(\alpha)\right)_{n\times n} = \left(p_{ij}^{\alpha} q_{ij}^{1-\alpha}\right)_{n\times n} \qquad \forall \alpha \in [0,1]$$

All components of matrix $D(\alpha)$ are convex combinations of corresponding components of the two matrices, P and Q. Moreover, it is a monotonic continuous function matrix constructed based on α. Therefore, simply observed, $D(1) = P$ and $D(0) = Q$ [52]. According to these characteristics:

- For each $\alpha \in [0,1]$ and $i,j = 1,2,\ldots,n$ we have $d_{ij}(\alpha) \in \left[a_{ij}, b_{ij}\right]$.
- P and Q are reciprocal matrices.
- $D(\alpha)$ can be defined as an interval comparison reciprocal matrix for any $\alpha \in [0,1]$.

Now we have matrix $\boldsymbol{A}$, which is an interval comparison reciprocal matrix, and a_{ij} and b_{ij}, which are non-negative values such that $a_{ij} \leq b_{ij}$, $a_{ij} = \frac{1}{b_{ij}}$, $b_{ij} = \frac{1}{a_{ij}}$. Thus, we can say that if P and Q have acceptable *CR*s, then matrix A also has an acceptable *CR*. Otherwise, matrix A is not consistent [35,53].

We use a convex combination technique for calculating the relative interval weightings. In this technique, we take advantage of the weightings of definite comparison matrix $D(\alpha)$, where $\alpha \in [0,1]$. Therefore, Suppose $w(\alpha)$ is the vector containing the weightings of matrix $D(\alpha)$ that resulted from the geometric mean method, then

$$w_i(\alpha) = \left(\prod_{j=1}^{n} d_{ij}(\alpha)\right)^{\frac{1}{n}} \quad (12)$$

where i = 1,2, ... , n and α ∈ [0,1].

Applies if: $\prod_{i=1}^{n} w_i(\alpha) = 1$. According to the definition of $d_{ij}(\alpha)$ we have

$$\begin{aligned} w_i w_i(\alpha) &= \left(\prod_{j=1}^{n} p_{ij}^{\alpha}\, q_{ij}^{(1-\alpha)}\right)^{\frac{1}{n}} \\ &= \left([\prod_{j=1}^{n} p_{ij}(\alpha)]^{\frac{1}{n}}\right)^{\alpha} \left([\prod_{j=1}^{n} q_{ij}(\alpha)]^{\frac{1}{n}}\right) \\ &= w_i^{\alpha}(P) w_i^{(1-\alpha)}(Q) \end{aligned}$$

where $w(P)$ and $w(Q)$ are weighting vectors for matrices P and Q, respectively. The weighting vector of $w(\alpha)$ that was obtained from the family of $D(\alpha)$ is used to make the interval weighting w_i, as below:

$$w_i = [\,\underline{w}, \overline{w}\,],\ \underline{w} = min\ \{w_i(\alpha)|\alpha \in [0,1]\} \text{ and } \overline{w} = max\ \{w_i(\alpha)|\alpha \in [0,1]\}$$

As for any $\alpha \in [0,1]$, $w_i(\alpha)$ (in which $i = 1, 2, \ldots, n$) is a monotonic continuous function based on α, the $\underline{w}$ and $\overline{w}$ can be defined as follows [53]:

$$\underline{w} = min\ \{w_i(P), w_i(Q)\} \text{ and } \overline{w} = \max\ \{w_i(P), w_i(Q)\}, \text{ then}$$
$$w_i = [\min\{w_i(P), w_i(Q)\}, \max\ \{w_i(P), w_i(Q)\}].$$

In the following, we used a simple statistical sampling method to calculate final weightings. The Monte Carlo simulation (MCS) was used to calculate the final weightings based on the $w_i = [\,\underline{w}, \overline{w}\,]$, (in which $i = 1, 2, \ldots, n$). MCS is a common statistical sampling approach that is used for complex systems. By using this simulation method, an average value was calculated as the final weight through a repeated number of random statistical samples between the $\underline{w}$ and $\overline{w}$.

3. Results

3.1. Results of Conventional AHP

This study was carried out to evaluate the current situation of Mersin's public bus transport system. The results of the presented study may also be analyzed group-wisely due to the different groups of participants. The characteristics of the conducted survey based on the hierarchical model were the following:

97 evaluators (2 managers 'in the relevant field' + 15 government officials 'in the relevant field' + 40 public passengers + 40 non-passengers) were asked to fill the questionnaires by comparing the criteria in the structured PCs. The selection of the non-expert participants can also be considered as purposive because of reflecting the characteristics of the total population of the city in the sample by age, gender and education. The survey was conducted in July and September 2017 and analyzed in December 2017.

In the case of some factors, significant discrepancies could be detected between the passenger, non-passenger and the governmental evaluators. Considering the separation of the three different viewpoints of public transportation and the impact of weights of each previous level (as AHP characteristic), the calculated weight vectors are presented below (note that for this survey no alternatives were used, only the weight scores of the criteria were analyzed). The scores of the proper eigenvectors provide the opportunity to set up a rank order of preferences among the participants of public transport on the issues of the system considering the weights of the previous levels (see Formula (6)) as well. The order of priority of the different elements of the public bus transportation systems in terms of their development is presented in Figures 2–4.

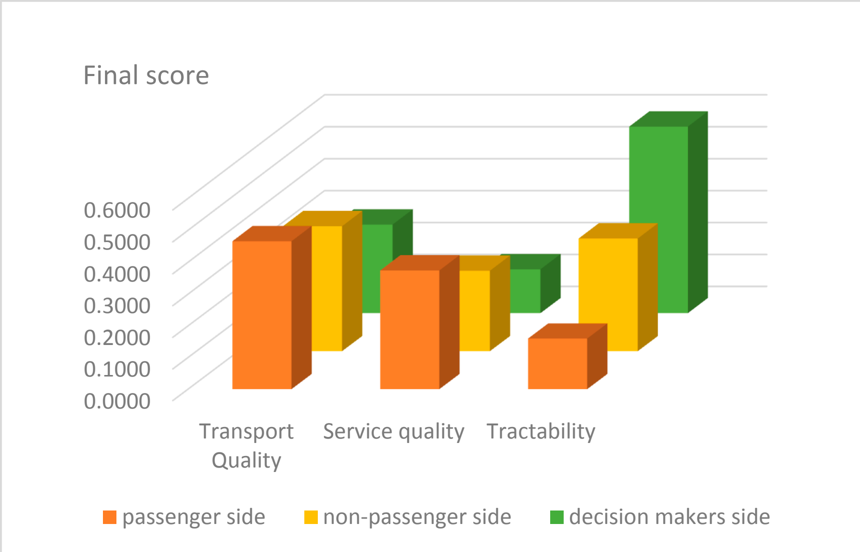

Figure 2. Final scores for different evaluator groups for Level 1.

At the first level, passenger and non-passenger evaluator groups of the analyzed public transportation system indicated the development of "transport quality" as the most essential issue; however, the decision maker group indicated the development of "Tractability" as the most essential issue. "Service Quality" development had approximately the same importance for decision maker and non-passenger participants, and it was more important for passengers.

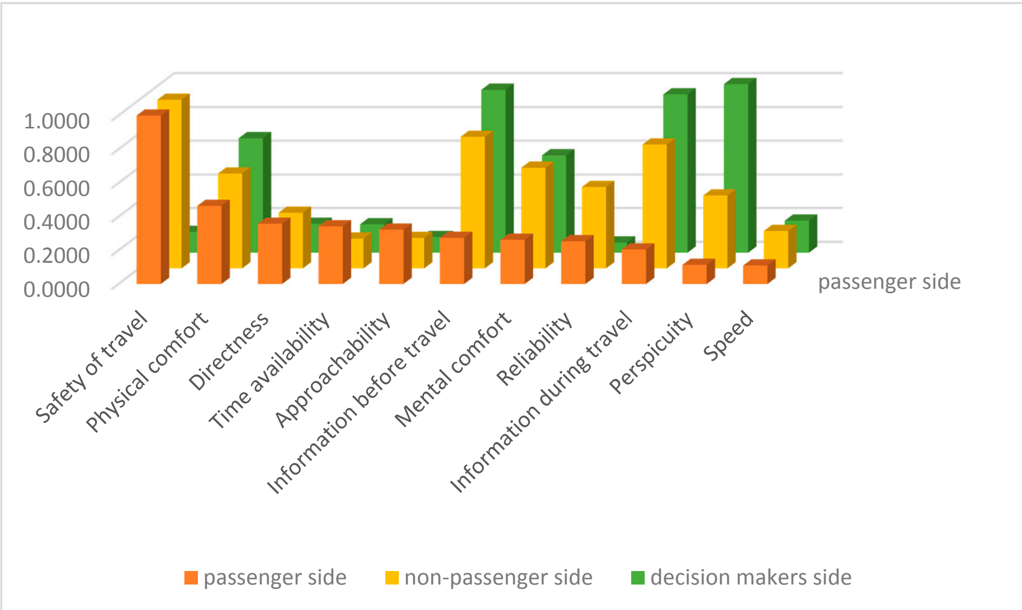

Figure 3. Final normalized scores for different evaluator groups for Level 2.

On Level 2, the "Safety of travel" issue was considered the most essential issue to develop for the passengers and non-passengers. However, a huge gap could be identified in the preference of the third stakeholder group; "Perspicuity" was the most important issue for decision makers followed by "Information before travel", "Information during travel" and "Physical comfort". This indicates that without the recent survey, a non-sustainable decision would likely have been made by the local government representatives with regard to developing the public bus transport system and citizen opposition could have been expected. The utilization of public vehicles is high in Mersin, and most of the time empty seats cannot easily be found easily, so improving "Physical comfort" might be necessary, and it was the second most important issue for passengers. The development of "Physical comfort", "Mental comfort", "Information before travel", "Information during travel" and "Approachability" have almost the same importance for both non-passengers and decision makers.

At the last level, "Frequency of lines" was the most essential issue to be developed for the passengers, followed by "Need for transfer", "Directness to stops" and "Fit connection". For the non-passengers "Fit connection" was the most essential issue, while this was of lesser importance for passengers (only ranked 4th) and for the decision makers (ranked 3rd). The "Directness to stops" was absolutely non-significant for non-passengers and government representatives. The development of "Comfort in stop" had almost the same importance for all parties. The waiting time had the same degree of importance for non-passengers and decision makers, and it was the least important issue for passengers.

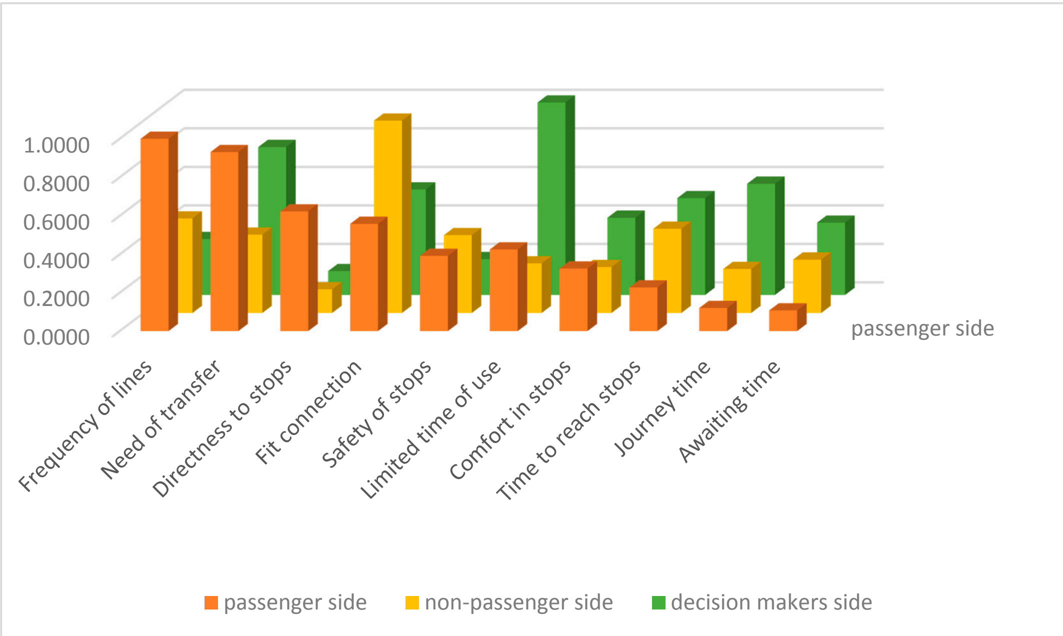

Figure 4. Final normalized scores for different evaluator groups for Level 3.

3.2. Results of IAHP

In this study, our approach was to use interval calculations to deal with the diversity in the opinions of our different target groups and reach a reliable overview based on the opinions of all respondents. The interval matrices of $A_{i\times i}$, (in which $i = 1, 2, \ldots, n$) were prepared based on the interval elements of x_{ij}, (in which $i, j = 1, 2, \ldots, n$) of all values used in the questionnaires. The minimum value of the pairwise comparisons represented by each group was considered as the lower bound (a_{ij}) for $x_{ij} = [a_{ij}, b_{ij}]$ and the maximum value was selected for the upper bound of (b_{ij}). Therefore, the generated interval pairwise comparison matrices consisted of all the preferences of the three groups (passengers, non-passengers, and decision makers). The *CR* of the calculations of both *P* and *Q* matrices were less than 0.1. Thus, according to the descriptions in Section 2.3, the matrix *A* also has an acceptable *CR*.

At the first level, interval pairwise comparison matrices indicated that the development of "transport quality" is the most important criterion at this level, while "service quality" development was ranked as having the lowest importance (see Figure 5).

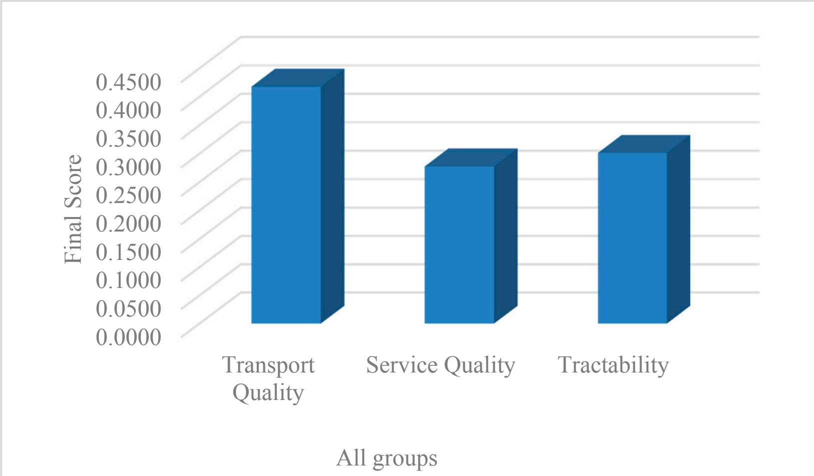

Figure 5. Final scores for all evaluator groups for Level 1.

At Level 2, the resulting weights "Information before travel", "Physical comfort", and "Information during travel", were higher than the other criteria, while, that of "Speed", "Reliability", and "Approachability" ranked lower than the eleven other criteria compared at this level. The weights of "Safety of travel" and "Mental comfort" were close, with values of 0.12 and 0.11, respectively. The results of this level were represented in Figure 6.

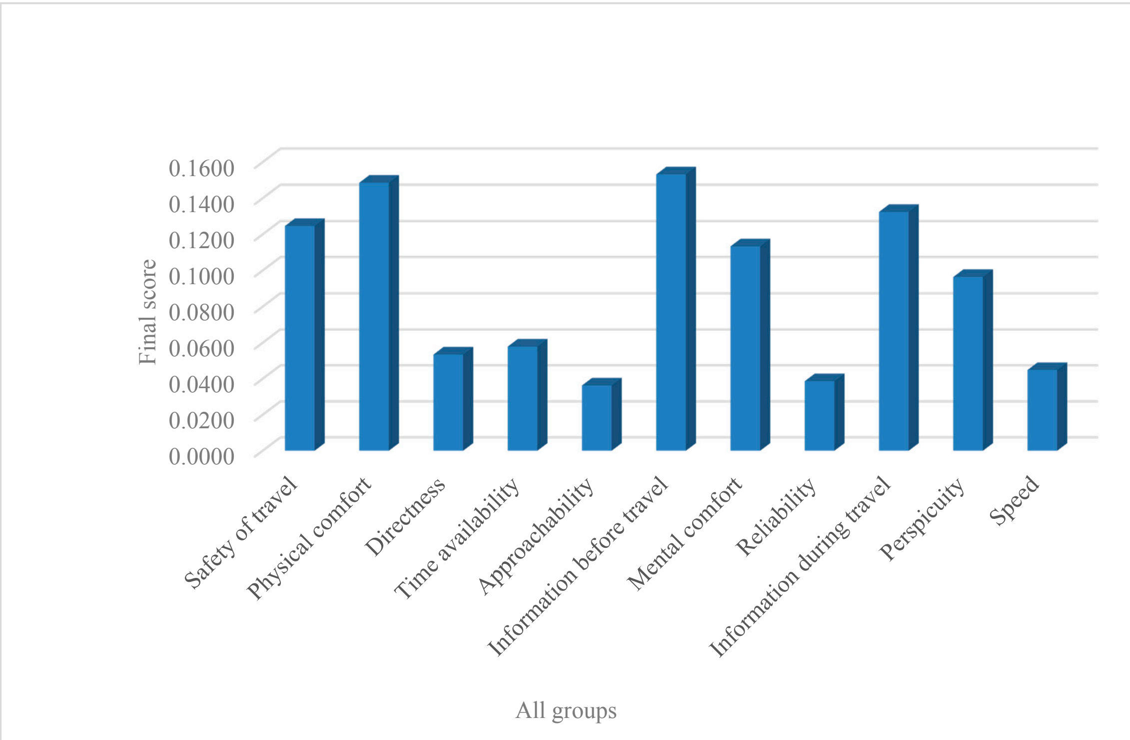

Figure 6. Final scores for all evaluator groups for Level 2.

At the third level, ten criteria were weighted and ranked (see Figure 7). At this level, "Fit connection" and "Limited time of use" were the most important criteria based on the comparisons of all groups. The results of this level indicated that "Awaiting time" was not as important as the other criteria and ranked lowest with a weight of less than 0.05.

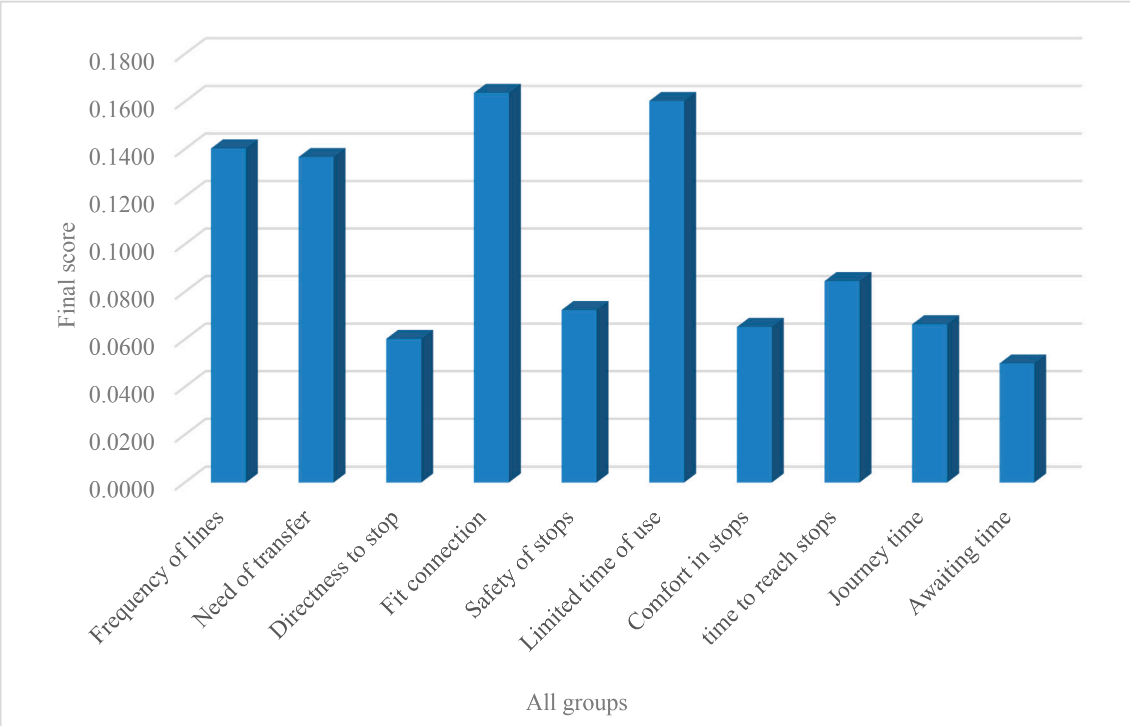

Figure 7. Final scores for all evaluator groups for Level 3.

4. Comparing Results and Discussion

MCDM is considered to be a solution for complex decision-making problems with an inevitable degree of uncertainty [54]. The significant uncertainty results from the criteria weightings in the MCDM [55]. The AHP approach is one of the most applied MCDM methods imposes a hierarchical structure on problems. The AHP approach is popular due to the simplicity of obtaining the criteria weights based on expert knowledge [35] but it suffers from inner and outer interactions, with little feedback between the different components and alternatives in the decision-making process [56]. Moreover, any inaccurate comparison of experts in the PCMs can be directly transferred to the weights and thus impact the criteria ranking [57]. An inaccurate comparison can arise for different reasons, such as misunderstandings, an incomplete understanding of the criteria, and particular motivations and interests of the different groups or even individual experts and respondents regarding the comparisons. In our case, when we asked participants from different groups to complete the PCMs, the third reason would be the main factor contributing to the uncertainty and inconsistency in our results. This matter is completely evident in the resulting AHP weights for all three levels. At the first level, passengers and decision makers have a completely opposite view about "Transport quality" and "Tractability", which resulted from the different preferences of these groups (see Figure 8). At the second level, as visible in Figure 9, although there are some similarities between the expectations of our target groups about criteria such as "Physical comfort" and "Speed", significant discrepancies between the resulting criteria weights of "Safety of travel" and "Perspicuity" make it difficult to define measurements to develop the system in a sustainable way. Also at the third level inconsistencies and incommensurability between the AHP weights exist. Significant differences exist between the opinions of the passengers and the decision makers, especially when comparing the criteria "Frequency of lines" and "Directness to stops" at level 3 (see Figure 10).

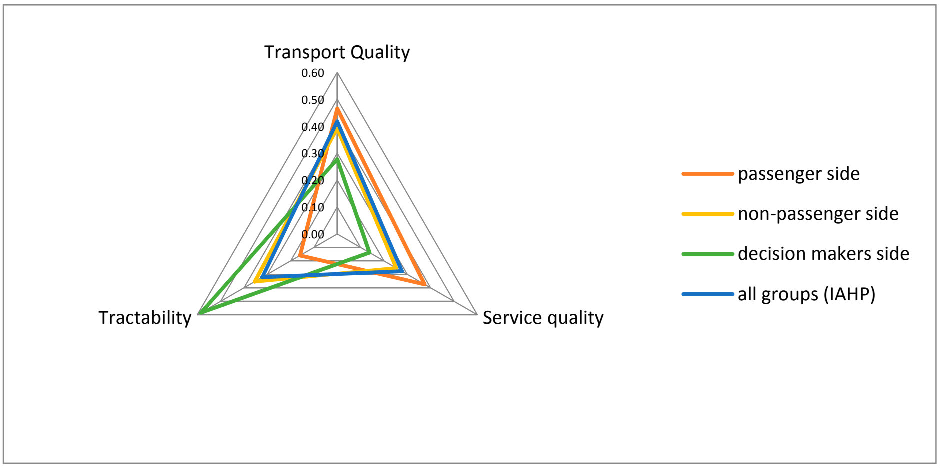

Figure 8. Comparing results of the analytic hierarchy process (AHP) and the Interval-AHP (IAHP) at Level 1.

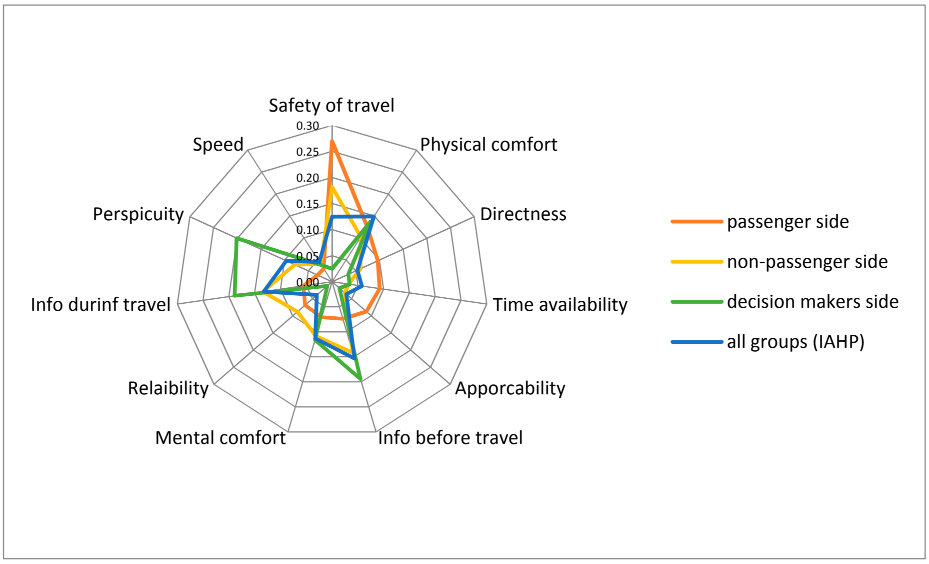

Figure 9. Comparing results of the AHP and the IAHP at Level 2.

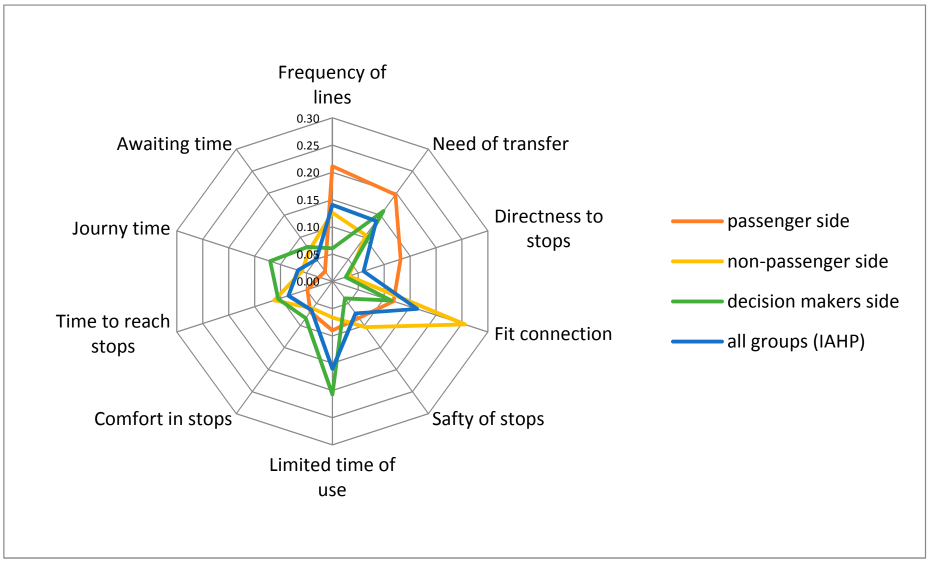

Figure 10. Comparing results of the AHP and the IAHP at Level 3.

Although based on the AHP results, the weightings of comparisons of the non-passengers are usually on average between those of passengers and decision makers, there are also some significant differences compared to the other groups for the criteria "Fit connection" and "Limited time of use". Therefore, it is difficult to isolate some particular suggestions for the development of the public transportation system in Mersin. We may reconfirm the need for optimizing the conventional AHP. Our research developed an IAHP approach that could provide final results that are more comprehensive and able to be applied for further decision-making. All weights resulting from the IAHP are considered in the comparisons of all of our target groups. Sensitivity analysis showed our stability ranking of the factors. Thus, these weights can be regarded to be representative for a public opinion and the results are useful for a final decision that contributes to a more sustainable transport system by favouring developments that meet the preferences of the three groups studied.

5. Conclusions

In this research, we presented an interval calculation for optimizing the classic AHP decision support approach, called IAHP. The main purpose of our research was to create a more comprehensive survey of all stakeholders to develop the public transportation system in a sustainable and consensual way to avoid potential opposition of some groups of citizen. We illustrated the differences between the results of the survey-based AHP for different groups of experts and citizens. These results revealed a significant discrepancy between opinions of recent passengers, non-passenger citizens and decision makers for most of the criteria weights. These anticipated discrepancies confirm the results of earlier studies. In 2012, a survey on supply quality development was conducted in the city of Yurihonjo by three participant groups; local government representatives, transport company managers and passengers [6]. In that case, service quality and within that, approachability got the highest importance (which resulted in the replacement of some bus stops) and on the third level, frequency of lines was ranked first. However, for the Yurihonjo case, it was clearly stated that preferences of different stakeholders differ and a methodological solution is necessary to reach a sustainable solution. Our research used an optimization technique to deal with some of the known problems of criteria comparison. Our results confirm that IAHP can support a more encompassing approach for a consensual development of a public transport system.

A possible limitation of the introduced model is that in cannot explain causalities: it is not clear which proportion of the difference in ranking is due to the lack of expertise or information of the citizens and how much of the difference is due to the different incentives of the groups. In the future, the MAMCA approach could be extended to identify such causalities. Nevertheless, through the application of our model, a more consensual final result could be obtained that can definitely be considered as more sustainable than merely applying the traditional AHP methodology. In our future research, we envisage the comparison of this new IAHP model with other possible group consensus creation models such as techniques based on vector distance minimization.

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