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A Comparative Analysis of Homogenous Groups' Preferences by Using AIP and AIJ Group AHP-PROMETHEE Model

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Abstract: Preference surveys often strive to reveal the perceptions of respondents with different demographic and habitual characteristics to reflect the features of a local community or city. However, the target group can be considered a priori homogenous in some cases, which requires an adjusted survey methodology. Apart from the smaller sample size, the aggregation technique of the individual preferences into a global common priority is also different in these types of problems according to the decision science principles. Interestingly, this feature is often ignored in group multi-criteria decision-making problems, especially in PROMETHEE model applications. This paper aims to apply the Aggregation of Individual Judgement technique in PROMETEHEE AIJ-PROMETHEE via the introduction of a hybrid Group AIJ-AHP-PROMETHEE model, specifically designed for homogenous group preference problems, to be compared with the conventional Aggregation of Individual Priorities (AIP). The new AIJ-AHP-PROMETHEE model, which is more suitable for homogenous groups, is less costly and less time-consuming than the general aggregations. The effectiveness of this new model is emphasized with real data, surveying university students' perceptions of different transport modes in the city of Budapest. Results show considerable findings of the introduced model and its general applicability to the evaluation of the public transport service quality system.

Keywords: AIJ; AIP; group PROMETHEE; group AHP; service quality; public transport

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1. Introduction

In transport surveys, researchers pay special attention to applying representative data to their analysis to validate the results gained from the pattern to the global targeted community [1,2]. Consequently, in revealing group preferences, the size of the pattern is recommended to be as large as possible [3], and the demographic characteristics of the pattern should reflect the whole community [4]. In case the target group or the specific community we want to survey can be considered homogenous from demographic or other points of view (e.g., commuters or all group members share the same travel habits), the survey methodology should be adjusted to the special situation [5,6]. Evidently, the more homogenous the group we want to survey is, the smaller the necessary sample size because of the higher probability of preference fitness between the pattern and the whole group. However, is this the only difference caused by the a priori knowledge of the homogeneity of the examined group? Can we not take advantage of these very important characteristics and apply a different survey methodology to determine the global preference of the group more accurately?

Our recent paper aims to introduce a new hybrid multi-criteria decision–making model for group preference analysis and apply the AIJ approach in PROMETHEE, which considers the homogeneity of the survey group and thus applies a different preference aggregation than the conventional Aggregation of Individual Priorities method. Generally, there exist two group aggregation approaches deployed in literature, the Aggregation of

Individual Priorities (AIP) and Aggregation of Individual Judgements (AIJ). For several group decision problems, the conventional solution is the application of AIP [7], i.e., each evaluation is analyzed first and then their aggregation is computed. However, there is a clear distinction in the literature regarding the usage of AIJ and AIP. Several researchers find agreement in applying the AIJ in case the target group is homogenous and assumed to act as a unit [8], while AIP is recommended when the group is heterogeneous and is seen as a collection of independent agents maintaining their own identities [9].

Multi-Criteria Decision-Making (MCDM) provides a variety of methods to solve complex studies [10–12]. The most popular MCDM methodology applied in surveying preferences in the field of transportation is the Analytic Hierarchy Process (AHP) [13–15]. It is recognized for its simplicity and efficiency in weighing attributes, through pairwise comparison (PWC) matrices according to Saaty's scale [16]. However, the PROMETHEE method (Preference Ranking Organization METHod for Enrichment Evaluation) is also proving great advantages in outranking alternatives through qualitative and quantitative evaluations besides eliminating scaling effects by using preference functions [17]. In the literature, for multiple decision-makers, the conventional group PROMETHEE decision support system enables one to aggregate different opinions via the aggregation of the individual priorities presented first by the authors [18] and applied in different fields to solve complex problems and outrank alternatives [19,20]. However, the introduced model aggregates individual judgements (AIJ) for both MCDM methods (AHP and PROMETHEE) for a two-level hierarchical criteria structure that was successfully applied in previous studies [21,22]. The AIJ approach is recommended for a homogenous group of decision-makers acting as one individual [23], which is the case of this study that aims to evaluate the preference mode choice for university students expecting similar service quality from the public transport system, as it is a significant factor to attract users [24,25]. Additionally, a comparative analysis is presented to compare both approaches (AIP and AIJ) in terms of outcomes, time, cost, and visibility. AHP and PROMETHEE have positive mutual relation in solving complex problems with consensual integrated models to outrank alternatives and point out optimal solutions [26]. AHP strengthens the model and assigns weights to criteria for a hierarchical structure by using pairwise comparison according to Saaty's scale [16,27], PROMETHEE outranks alternatives based on tangible and intangible attributes, and GAIA uses features that present a huge advantage for the AIJ-AHP-PROMETHEE approach in introducing cardinal outputs and visualizing the interaction between attributes and the decision axis, as well as estimating the results' stability by conducting sensitivity analysis [28,29].

In the coming sections, we present an overview of the existing literature in Section 2, a detailed description of the deployed methods (AHP, PROMETHEE, AIP, AIJ), and the introduced model are presented in Section 3. The results of both approaches and the comparison of the constructed AIJ-AHP-PROMETHEE approach with the conventional one are demonstrated in Section 4, while the discussion and conclusions are highlighted in Sections 5 and 6, respectively.

2. Literature Review

Decision-making models are becoming very precise to solve complex problems by deploying hybrid models [30–32]. To collect multiple opinions, some methodologies are utilized in the literature to aggregate the evaluations, such as the aggregation of individual priorities [8,23,33], which is used in the case of a heterogeneous group of decision-makers, as well as the aggregation of individual judgement that is recommended for a homogeneous group of evaluators [34,35]. Few research studies discuss the AIJ and AIP approaches for the AHP method. The authors of [33] confirm that the AIP approach enables one to capture the uncertainty of the individuals and the context. Ref. [35] compares fuzzy AHP and AIJ-AHP to highlight the applicability of this approach. Furthermore, Ref. [36] presented a model to aggregate preferences for a group of evaluators and concluded that the approach provides flexibility and inconsistency reduction. However, for the PROMETHEEE method, the AIP is widely used for group evaluations, as in the case in [19], to better describe common characteristics in the evaluation of a heterogeneous group. Additionally, the authors of [37] introduced a model that aggregates PROMETHEE priorities to select the optimum scenario for waste treatment. Our paper aims to introduce a comparative analysis between AIJ and AIP methodologies for Group AHP-PROMETHEE to assess the service quality of public transportation modes to evaluate the applicability of AIJ-AHP-PROMETHEE. To the best of our knowledge, there is no application of AIJ-PROMETHEE in the literature that can be considered a novelty. The comparative analysis between these two models highlights the effectiveness of the new approach, as well as the sensitivity analysis that can be used only for the case of AIJ-PROMETHEE as decision-makers are considered as one individual [38].

Sustainable public transportation is an essential objective that policymakers and experts are striving for. Ref. [39] applied the AHP method to investigate stakeholders' consensus for sustainable transportation to develop an urban mode. Ref. [40] identified the factors to take into consideration for sustainable travel modes to promote public transport modes among students. The authors of [41] proved the potential advantages of mobility as a service in sustainable transportation. Furthermore, the research [42] discussed sustainable urban transportation to improve bus services for different stakeholders using the AHP-Kendall model. The AHP method is significantly applied in decision-making projects including in the transportation field. It provides simple and understandable results to participants [43–45]. The PROMETHEE method contributes to solving complex problems in decision making in different critical fields such as nuclear and healthcare [46,47]. Previous research [48] deployed the PROMETHEE method for outsourcing third-party logistics for a case study in China. In urban public transport, PROMETHEE was not massively applied, and to the best of our knowledge, two studies have been conducted to exploit the advantages of this method in urban transport [20,49].

Our paper presents a comparative analysis of two approaches to highlight the uniqueness of the newly constructed model. Our contributions are as follows:

- Elaborate on a new model, AIJ–Group AHP–PROMETHEE, to evaluate urban public transport.
- Comparative analysis with the conventional AIP approach to testing the applicability of the new model.
- Sensitivity analysis for the PROMETHEE outputs is possible for the AIJ approach and is not applicable in the case of the AIP approach because of the final aggregation.

To stress the paper's novelty and compare it with existing research about MCDM and public transport service quality, Table 1 gives an overview of the literature review.

Table 1. A summary of the literature review.

Reference	Model	Methodology
F. Lolli, et al. [37]	Group Fuzzy PROMETHEE	The AIP approach to select the optimum waste treatment
Jelena J. Stankovic, et al. [50]	PCA–PROMETHEE	Principal component analysis and PROMETHEE method to evaluate the development of the circular economy
Juan de Ona, et al. [51]	Statistical analysis	A statistical approach to analyze public and private service quality
Díez–Mesa, et al. [52]	Structural Equation Modelling	Evaluation of Underground mode service quality by using Structural equation modelling approach
P. Amenta, et al. [53]	Group AHP	The AIJ approach to aggregate decision makers evaluations into a common group preference matrix
M. Escobar, et al. [33]	Group AHP	The AIP approach for group AHP method
L. Turcksin, et al. [28]	AHP–PROMETHEE	Combination of two MCDA methods and the exploit of GAIA plane to promote clean fleet factors
A. Alkharabsheh, et al. [54]	Group AHP	The AIJ group AHP for the evaluation of passenger demand for public transport
L. Oubahman, et al. [20]	Group PROMETHEE	AIP approach to aggregate the final scores of PROMETHEE method computed for every decision maker

Table 1. *Cont.*

Reference	Model	Methodology
Hsu–Shih Shih [55]	Group PROMETHEE	The enhancement of threshold determination for a group of decision makers in PROMETHEE I, II and III
Proposed model	Group AHP–Group PROMETHEE	The AIP approach for the model Group AHP-PROMETHEE The AIJ approach for the model Group AHP-PROMETHEE Comparative analysis between both approaches Cardinal outputs and sensitivity analysis of the AIJ Group AHP-PROMETHEE model, GAIA plane Application of the new model to evaluate urban public transport service quality

3. Materials and Methods

This paper is a combination of two MCDM methods (AHP, PROMETHEE) that are applied in two different approaches (AIP, AIJ); the first one is conducted to aggregate individual priorities (AIP) by utilizing the arithmetic mean of the net flows computed in PROMETHEE II, and the second approach aggregates evaluators' individual judgements (AIJ) in order to calculate positive, negative, and net flows with PROMETHEE I and II.

3.1. AHP Method

The MCDM AHP method is well known for its effectiveness in simplifying complex problems. It requires three principal phases, namely elaborating hierarchical structure for attributes, building pairwise comparison matrices for every level of criteria descending from the same element, and an evaluation by decision-makers based on Saaty's scale as shown in Table 2.

Table 2. Judgement scale of relative importance for pairwise comparisons (Saaty's 1–9 scale).

Numerical Values	Verbal Description
1	Equal importance of both elements
3	Moderate importance of one element over another
5	Strong importance of one element over another
7	Very Strong importance of one element over another
9	Absolute importance of one element over another
2,4,6,8	Intermediate values

It is worth mentioning that the matrix eigenvector for pairwise comparison is calculated as follows:

$$A \cdot w = \lambda_{max} \cdot w, \tag{1}$$

$$(A - \lambda_{max} I) \cdot w = 0, \tag{2}$$

where A is the consistent matrix, w is the eigenvector, λ_{max} is the maximum eigenvalue, and I is a unit quadratic matrix with a diagonal equal to 1.

A consistency check is mandatory when decision makers are not experts in the decision-making process [42]. Some conditions have to be fulfilled.

Reciprocity condition:

$$a_{ij} = \frac{1}{a_{ji}}, \tag{3}$$

Transitive condition:

$$a_{ij} = a_{ik} * a_{kj} \; \forall \; i, j, k \; \in \{1, \ldots, n\}, \tag{4}$$

where a_{ij} is the value in row i and column j in the matrix A, and n is the number of criteria.

The consistency ratio is calculated to ensure that the elaborated matrices values are consistent by using Saaty's eigenvector method [16].

The Consistency Index (CI) is calculated using Equation (5)

$$CI = \frac{\lambda_{max} - n}{n - 1}, \quad (5)$$

where λ_{max} is the maximum eigenvalue and n is the number of rows in a quadratic pairwise comparison matrix.

The Random Index (RI) is a random value provided by [16], and it depends on the size of the matrix. Table 3 shows different values of RI as a function of the size.

Table 3. Random Index (RI) from randomly generated matrices.

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

The Consistency Ratio should be inferior to 0.1 (CR < 0.1) [56], and it is calculated as shown in Equation (6).

$$CR = \frac{CI}{RI}, \quad (6)$$

With reference to the hierarchical structure for the sub-criteria, the final weights are computed as follows:

$$w_{Ai} = \frac{w_j}{\sum_{ja=1}^{m} w_j} \cdot \frac{w_{ij}}{\sum_{k=1}^{n} w_{ik}}, \quad (7)$$

w_j is the weight of the upper level, $\sum_{j=1}^{m} w_j$ is the sum of weights in the previous level, $j = (1, \ldots, m)$ is the number of elements in the previous level, w_{ij} is the eigenvector of the current level, $\sum_{k=1}^{n} w_{ik}$ is the sum of weights in the current level, $k = (1, \ldots, n)$ is the number of elements in the current level, and w_{Ai} is the new score calculated for the current level, with $(i = 1, \ldots, n)$.

Different approaches can be adopted to aggregate the values. The geometric mean avoids rank reversal, and it is used in our study for both approaches to aggregate individual judgements and individual priorities [56].

$$f(x_1, \ldots, x_k) = \sqrt[k]{\prod_{j=1}^{k} x_j}, \quad (8)$$

k is the number of evaluators participating in the study and $(x_1, x_2, \ldots, x_k)$ represent the same position entries in pairwise comparison matrices in the case of AIJ and the final criteria's weights for AIP.

3.2. PROMETHEE Method

The PROMETHEE method has two main steps to comprehensively outrank the alternatives. It is characterized by tangible and intangible evaluations with the use of preference functions. PROMETHEE deals with a trade-off in the partial ranking and enriches dominance in the comprehensive ranking via the elimination of the incomparability identified in PROMETHEE I [57]. In this study, we use two preference functions; the usual criterion and quasi-criterion functions. Both functions are explained in the equations below.

Type I: Usual Criterion

$$P(d) = \begin{cases} 0 & if\ d \leq 0 \\ 1 & if\ d > 0 \end{cases}, \quad (9)$$

Type II: Quasi-criterion

$$P(d) = \begin{cases} 0 & if\ d \leq q \\ 1 & if\ d > q \end{cases}, \quad (10)$$

q is the threshold defined by the decision-maker, P is the preference function, and d is the substruction of the values assigned to different alternatives for the same criterion.

3.2.1. PROMETHEE I

PROMETHEE I enables one to calculate the positive flow $\varphi^{+}(a_i)$ and the negative flow $\varphi^{-}(a_i)$.

The positive flow φ^{+}

$$\varphi^{+}(a_i) = \frac{1}{n-1}\ \sum\nolimits_{a_{i'} \epsilon A - \{a_i\}} \sum\nolimits_{j=1}^{m} P_j(a_i, a_{i'}) * w_j, \tag{11}$$

The negative flow φ^{-}

$$\varphi^{-}(a_i) = \frac{1}{n-1}\ \sum\nolimits_{a_i \epsilon A - \{a_{i'}\}} \sum\nolimits_{j=1}^{m} P_j(a_i, a_{i'}) * w_j, \tag{12}$$

w_j *is the weight* $\{w_1, \ldots, w_m\}$ for m criteria with $\sum_{j=1}^{m} w_j = 1$, and P_j is the value of the preference function.

There exist three possible assumptions between two alternatives from PROMETHEE I. It can be a preference relation (P), an indifference relation (I), or incomparability (R). In every case, some conditions should be fulfilled.

Preference (P): $a_i \mathrm{P}^{\mathrm{I}} a$

$$if \quad \begin{cases} \varphi^{+}(a_i) > \ \varphi^{+}(a_{i'})\ and\ \varphi^{-}(a_i)\ < \varphi^{-}(a_{i'})\ or, \\ \varphi^{+}(a_i) > \varphi^{+}(a_{i'})\ and\ \varphi^{-}(a_i)\ = \varphi^{-}(a_{i'})\ or, \\ \varphi^{+}(a_i) = \varphi^{+}(a_{i'})\ and\ \varphi^{-}(a_i)\ < \varphi^{-}(a_{i'}) \end{cases}, \tag{13}$$

Indifference (I): $a_i \mathrm{I}^{\mathrm{I}} a_{i'}$

$$if \quad \varphi^{+}(a_i) = \varphi^{+}(a_{i'})\ and\ \varphi^{-}(a_i) = \varphi^{-}(a_{i'}), \tag{14}$$

Incomparability (R): $a_i \mathrm{R}^{\mathrm{I}} a_{i'}$

$$if \begin{cases} \varphi^{+}(a_i) < \ \varphi^{+}(a_{i'})\ and\ \varphi^{-}(a_i)\ > \varphi^{-}(a_{i'})\ or, \\ \varphi^{+}(a_i) > \varphi^{+}(a_{i'})\ and\ \varphi^{-}(a_i)\ < \varphi^{-}(a_{i'}) \end{cases}, \tag{15}$$

3.2.2. PROMETHEE II

PROMETHEE II reaches the comprehensive ranking and eliminates the incomparability identified in PROMETHEE I. it is calculated as a subtraction of the negative flow φ^{-} from the positive flow φ^{+}.

$$\Phi\ (a_i) = \varphi^{+}(a_i) - \varphi^{-}(a_i), \tag{16}$$

Two conclusions can be obtained from PROMETHEE II, based on the value of the net flow Φ. The higher the value of the net flow is, the more the alternative's preference increases.

Preference (P): $a_i \mathrm{P}^{\mathrm{II}} a_{i'}$

$$\Phi(a_i) > \ \Phi(a_{i'}), \tag{17}$$

Indifference (I): $a_i \mathrm{I}^{\mathrm{II}} a_{i'}$

$$\Phi(a_i) = \ \Phi(a_{i'}), \tag{18}$$

The PROMETHEE method visualizes the final ranking and interaction between attributes via GAIA plane features. The results are presented as cardinal outputs and provide a clear view of how the attributes are interacting. Criteria oriented in the same direction express similar preferences; otherwise, they have different preferences, and the optimum solution has the same direction as the decision axis. Sensitivity analysis is a major advantage of the GAIA plane, and it shows the impact of changing weights on the final ranking and evaluates the robustness of the comprehensive ranking.

3.3. Aggregation of Individual Priorities

The AIP approach is based on the aggregation of the final results of the model. The computation of the evaluations is performed separately for each decision-maker for both AHP and PROMETHEE methods. Attributes values are aggregated using the arithmetic mean to calculate the global evaluation and outrank the alternatives according to the aggregated evaluations introduced in [18], as seen in Equation (19).

$$\Phi_G(a) = \frac{\sum_{h=1}^{k} \Phi_h(a)}{k}, \tag{19}$$

$\Phi_G(a)$ is the global net flow of the alternative $a \in A$, and k is the number of decision makers.

3.4. Aggregation of Individual Judgements

This approach aims to aggregate individual judgements of the AHP and PROMETHEE methods before evaluating the performance of criteria and alternatives. In order to avoid rank reversal, the geometric mean is used to aggregate the individual pairwise comparisons of the AHP method by applying Equation (8) [23], whilst for PROMETHEE, the arithmetic mean of objective and subjective values is calculated. Then, the quantification of positive and negative flows in PROMETHEE I and net flows in PROMETHE II is the next step to evaluate and outrank the alternatives.

The steps of the conducted approaches are summarized and presented in Figure 1.

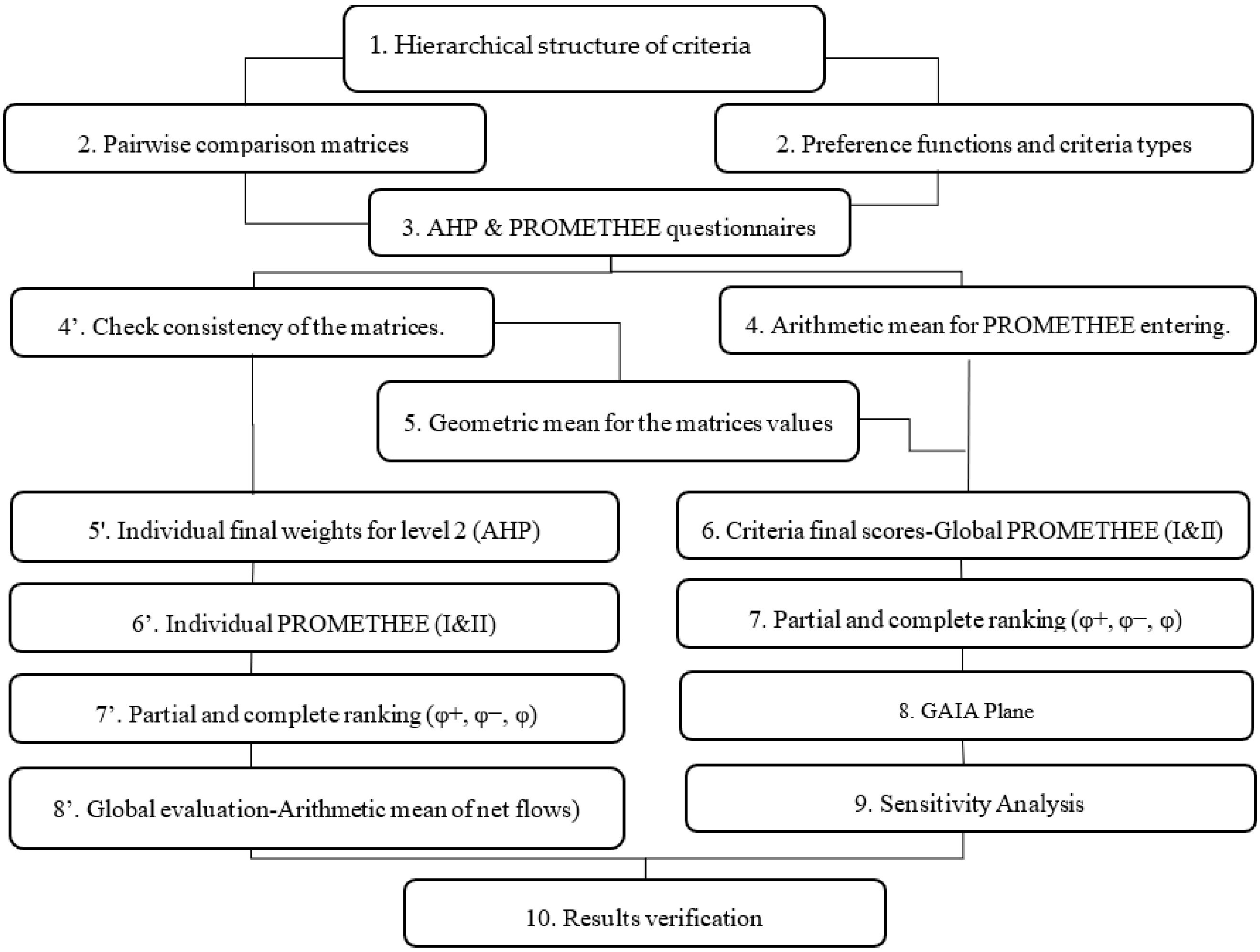


Figure 1. Methodology's description.

Step 1: In the first stage, we used a hierarchical structure that contains criteria to evaluate the service quality of urban transport [58].

Step 2: PROMETHEE: Considering the selection of preference function for criteria, in this study, we utilized the usual criterion function for quantitative attributes and quasi-criterion for qualitative ones.

AHP: The identification of pairwise comparison matrices to be evaluated based on the hierarchical structure.

Step 3: According to the chosen characteristics in step 2, the questionnaire is employed. The same questionnaire information is used in both models.

The first three steps are the same for both models, and the further steps are different.

For the AIP AHP–PROMETHEE model (Steps 4′, 5′, 6′, 7′, 8′): The calculation is performed for each evaluation separately for the AHP method to calculate the weights to be allocated to the criteria to compute PROMETHEE flows (φ+, φ−, φ). The aggregation of the set of these flows is performed using the arithmetic mean to rank the alternatives.

For the AIJ AHP-PROMETHEE model (steps 4, 5, 6, 7, 8, 9): To aggregate the PROMETHEE judgements, the arithmetic mean is employed; however, for AHP, the geometric mean is computed to avoid rank reversal. All evaluations will act as one, then we proceed to calculate PROMETHEE I and II. This approach enables one to obtain cardinal outputs via the GAIA plane, which can be exploited for sensitivity analysis.

The final step (10) in the methodology is the comparison between both models to test the applicability of the new proposed AIJ–AHP–PROMETHEE model.

4. Results

A case study is conducted to evaluate public transportation modes, as it has great importance in facilitating citizens' daily life. Public transport passengers are the decision-makers in this study. The selected pattern is (university students), which is a homogeneous group expecting similar services. We have constructed a comprehensive questionnaire in November and December 2020 with three sections; general and demographical information in the first section, AHP data in the second section, and the questions were formed in a way to be able to elaborate on the pairwise comparison matrices. PROMETHEE values are observed in section three, and real values are declared by evaluators according to their experience (i.e., Time to reach stop, frequency of lines, etc.). For the two-level hierarchical structure, five pairwise comparison matrices have been introduced to compute the weight values allocated to each criterion. The survey has been held in Budapest city, which is characterized by various modes of public transportation (bus, tram, underground mode). One hundred evaluations have been collected, and this number of samples is representative from an MCDM point of view as it provides a profound evaluation of the study via the pairwise analysis [16].

The service quality elements are presented in Figure 2 [58], while the explanation is outlined in Table 4.

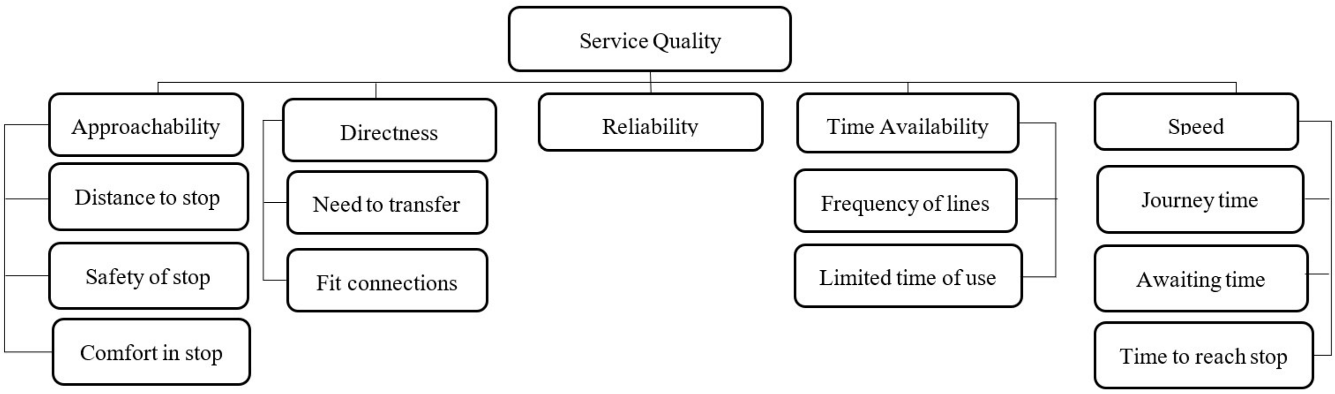


Figure 2. Public transport service quality model.

Table 4. Interpretation of service quality attributes.

Criteria	Adopted Nomination in Figures	Interpretation
Service quality	-	All provided services except on-vehicle and information services
Approachability	-	Line access
Directness	-	Ability to reach the destination without shifting vehicles
Reliability	-	Respecting planned schedules
Time availability	-	Time frame of line operation
Speed	-	The speed of travelling process
Distance to stop	Distance	Proximity of origin stations
Safety of stop	Safety	Subjective feeling
Comfort in stop	Comfort	Seats, cooling system, heating system
Need to transfer	Transfer	Need to change the vehicle to reach the destination
Fit connections	Connections	Time connection between lines to reach the destination
Frequency of lines	Frequency	Frequency of buses, Trams and Underground modes
Limited time of use	Limited.time	Time between the first and the last line of a day
Journey time	Journey.time	The time between on-board and getting off the vehicle
Awaiting time	Awaiting.time	Waiting time in the station for the line
Time to reach stop	Time.to.stop	Time to reach the origin station

4.1. The Aggregation of Individual Priorities

Evaluations are considered separately, and AHP final scores and PROMETHEE flows are computed for every evaluator. One hundred sets of AHP weights and 100 partial rankings (PROMETHEE I) and complete rankings (PROMETHEE II) are calculated. Visual PROMETHEE software has been used to calculate PROMETHEE flows.

The same procedure to calculate PROMETHEE flows is followed for all evaluations. The global evaluation is the arithmetic mean of computed flows [18].

The global partial ranking (PROMETHEE I) of public transport mode according to 100 evaluators considers underground mode as the best transportation mode, followed by tram and bus modes, based on entering and leaving flow values.

The global comprehensive evaluation (PROMETHEE II) results in the same ranking as the partial ranking, preferring 'Underground mode', with 'Tram' mode ranked second followed by 'Bus' mode (please see Table 5).

$$\Phi_{G\ (AIP)}(Underground\ mode) > \Phi_{G\ (AIP)}(Tram) > \Phi_{G\ (AIP)}(Bus), \tag{20}$$

Table 5. AIP-PROMETHEE final ranking.

AIP	$\varphi^{+}_{G\ (AIP)}$	$\varphi^{-}_{G\ (AIP)}$	$\Phi_{G\ (AIP)}$	Ranking
Bus	0.085018	0.252672	−0.16765	3
Tram	0.148229	0.130923	0.017306	2
Underground	0.231249	0.080907	0.150339	1

4.2. The Aggregation of Individual Judgements

Before starting the evaluation process, individual judgements were aggregated for both AHP and PROMETHEE methods. The geometric mean was used to aggregate AHP evaluations, and the procedure for computing the final scores of the second-level criteria is performed only once. Table 6 presents computed weights for the first and second levels of the public transport service hierarchical structure. The speed criterion from the first level is ranked in the first position, and this means that evaluators prioritize vehicle speed over other criteria. Time availability is ranked second with significant importance assigned by evaluators, followed by directness, reliability, and approachability as less important criteria. It is worth mentioning that even though the criterion reliability has no sub-levels, mathematically, it does not bias the calculation of the weights [21].

Table 6. Computed weights for individual judgement aggregation.

First Level Criteria	Weight	Ranking	Second Level Criteria	Local Weight	Local Ranking	Final Weight	New Ranking
Approachability	0.13695723	5	Distance to stop	0.30313998	9	0.04151721	9
			Safety of stop	0.58742974	1	0.08045275	7
			Comfort in stop	0.10943029	10	0.01498727	10
Directness	0.20093286	3	Need to transfer	0.49852044	4	0.10016914	4
			Fit connections	0.50147956	3	0.10076372	3
Time availability	0.23720442	2	Frequency of lines	0.45573878	5	0.10810325	2
			Limited time of use	0.54426122	2	0.12910117	1
Speed	0.25002706	1	Journey time	0.31907272	8	0.07977681	8
			Awaiting time	0.35912068	6	0.08978989	5
			Time to reach stop	0.3218066	7	0.08046036	6
Reliability	0.13981934	4					

The first-level criteria influence the final scores of the sub-level criteria, and limited time of use has gained one position as it was ranked second in the local ranking and moved to first because of the importance allocated to its parent criterion time availability, which is ranked second. The frequency of the line from the same branch moved to second from fifth in the local ranking. Waiting time and time to reach stop gained one position from sixth and seventh positions, respectively, to fifth and sixth positions, because the speed criterion was ranked first in the previous level. The safety of stop criterion from the approachability branch was ranked fifth in the first level and lost its importance from first in the local ranking to seventh in the modified scores. The distance to stop, comfort in stop, need to transfer, fit connections, and journey time criteria remained in the same positions even though the weight values were impacted.

The PROMETHEE method values defined by decision-makers are aggregated using the arithmetic mean to calculate group evaluations. However, the final weights of second-level elements are utilized in the PROMETHEE model to rank three transportation modes in Budapest city (Bus, Tram, Underground mode). It is important to highlight that both the safety of stop and comfort in stop criteria were evaluated as qualitative criteria; the aggregation of their entries was performed with numerical equivalent values to be precise about group evaluation.

PROMETHEE I determines partial ranking φ^+ and φ^- for each alternative. In this case, an incomparability relation has been detected (please see Table 7) between underground and tram modes. This incomparability is translated in the left visualization in Figure 3 as an intersection between two segments of tram and underground modes, which shows a situation of uncertainty that cannot lead to any decisive action.

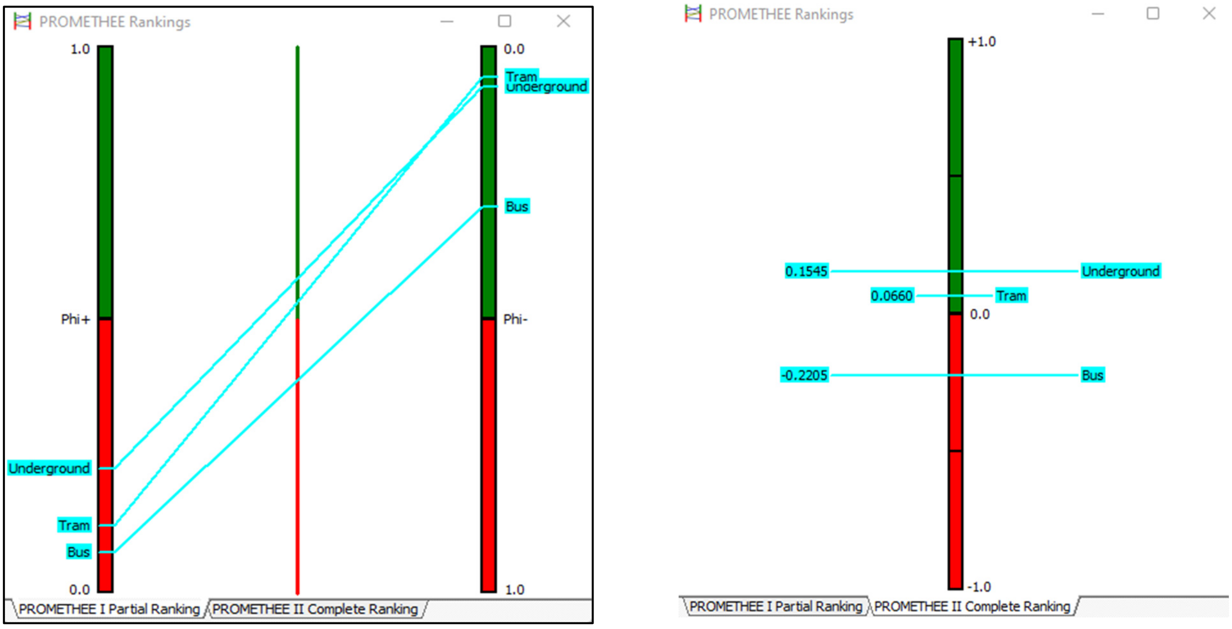
Table 7. AIJ-PROMETHEE final ranking.

AIJ	$\varphi^+_{G\ (AIJ)}$	$\varphi^-_{G\ (AIJ)}$	$\Phi_{G\ (AIJ)}$	Ranking
Bus	0.0729	0.2934	−0.2205	3
Tram	0.1223	0.0563	0.066	2
Underground	0.2274	0.0729	0.1545	1

We are able to conclude from this partial ranking that bus is in the third position because preference relations are verified for both modes. Furthermore, the left visualization (a) in Figure 3 shows that the bus segment is below other segments as a result of its highest value in entering flow φ^- and lowest value for leaving flow φ^+.

In order to decide between these two elements (tram and underground mode), it is crucial to proceed with PROMETHEE II for a comprehensive ranking. From Table 7 and the right visualization of Figure 3b, it is clear that the underground mode is ranked first followed by tram and bus in the last position.

$$\Phi_{\ G\ (AIJ)}(Underground\ mode)\ >\ \Phi_{\ G\ (AIJ)}(Tram)\ >\ \Phi_{\ G\ (AIJ)}(Bus), \tag{21}$$



(**a**) (**b**)

Figure 3. (**a**) PROMETHEE I and (**b**) PROMETHEE II ranking.

4.3. GAIA Plane and Sensitivity Analysis

The GAIA plane visualizes interactions between attributes and simplifies the problem's analysis and speeds up the decision-making process. Figure 4 shows that most criteria are pointing to the side of underground and tram modes. The length of the criteria axis is also important, whereby the longer the axis, the more discriminant the criterion. The need to transfer, fit connections, limited time of use, and waiting time factors are represented by the intersection point of (U-V) axes. The time to reach stop and distance to stop have the same uni-criterion evaluation, and they are overlapped in the visualization. The safety of stop and comfort in stop are also overlapped because of the same uni-criterion evaluation. The latter is the evaluation of alternatives depending on each criterion without considering the allocated weight.

Criteria with the same direction as the decision axis have good performance. In this study, journey time, comfort in stop, and safety of stop have similar preferences. Furthermore, these criteria have good performance in the case of the underground mode. The frequency of lines criterion is oriented in the same direction as the decision axis and is very close to the tram mode, which has good performance. The time to reach stop and distance to stop point in the opposite direction, explaining the conflict with other criteria, even though they have good preferences in the bus mode. The decision axis is pointing between tram and underground modes, and a decision-maker can understand that both alternatives are good options, which explains the incomparability detected in PROMETHEE I (see Table 7). The need to transfer, fit connections, limited time of use, and waiting time do not influence the GAIA plane because of their null values.

GAIA plane's quality is indicated as 100% and written in green color, and this indicates that 100% of the information is gathered (no information has been lost).

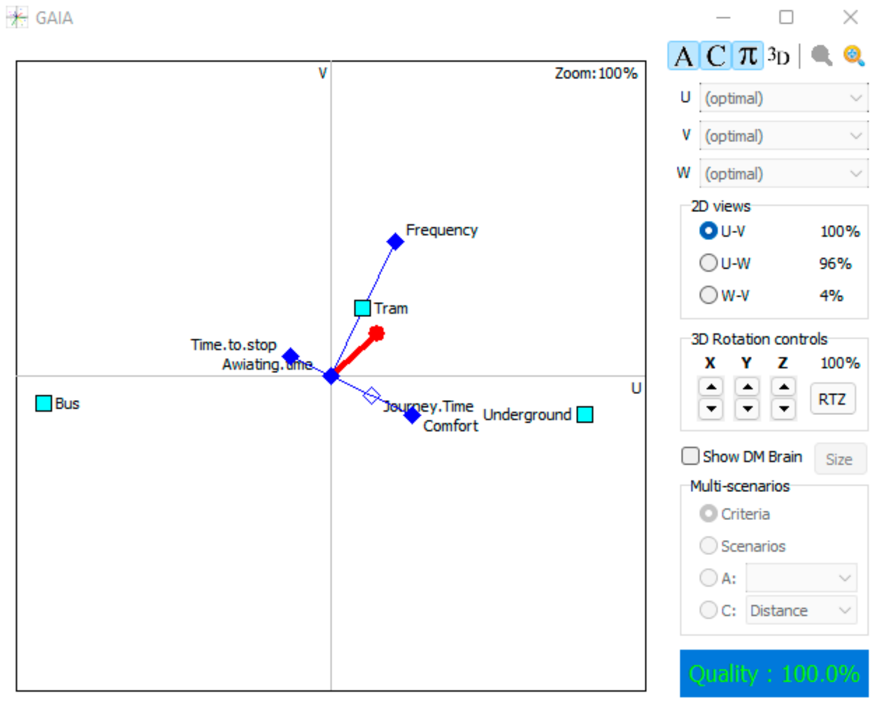


Figure 4. GAIA plane.

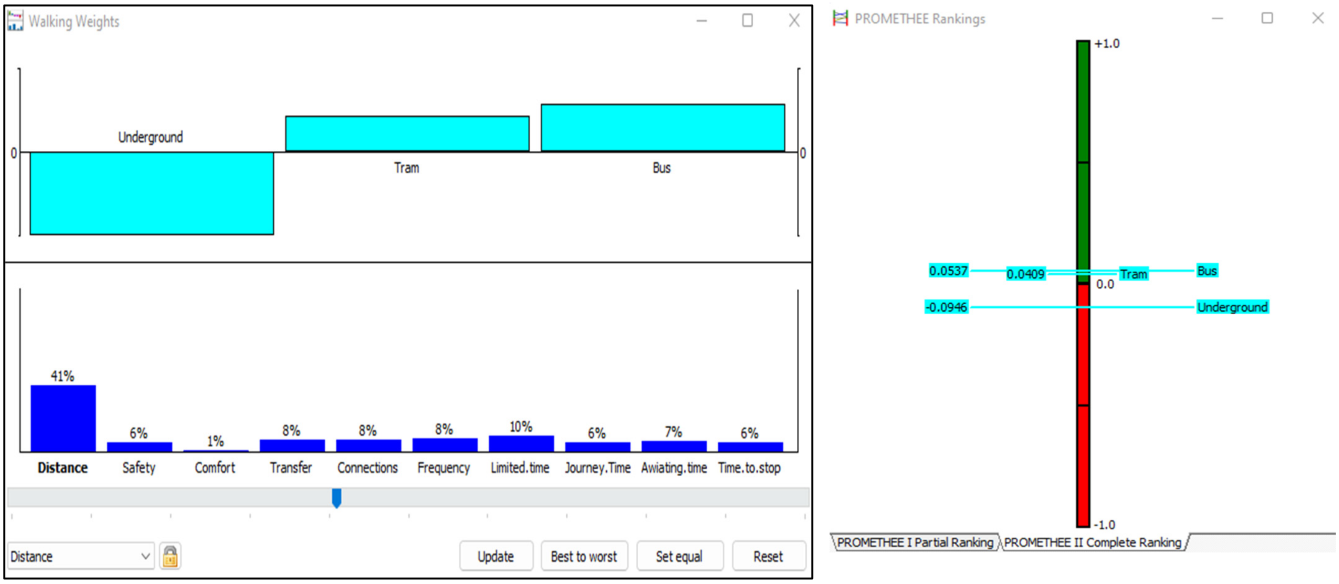
The sensitivity analysis is vital to test the results' stability. For this reason, it is worth identifying criteria with a good assessment for each mode. The time to reach stop and distance to stop criteria have similar preferences and good performance for the bus mode. The frequency of lines has a good evaluation for trams. The rest of the criteria have good performance for the underground mode. Figures 5 and 6 presents the criteria performance with respect to each alternative.

When criteria weights are modified during the sensitivity analysis process, the criteria visualization does not change; rather, only the direction of the decision axis changes and points in the direction of the optimum alternatives. By examining the feature of the Weight Stability Interval (WSI) in Table 8 it is clear that all criteria have wide range intervals, except the distance to stop [0%, 19.08%] and time to reach stop [0%, 23%]. These criteria are related because the distance and time are proportional. Both criteria are sensitive compared to other criteria.

Table 8. Weight stability intervals.

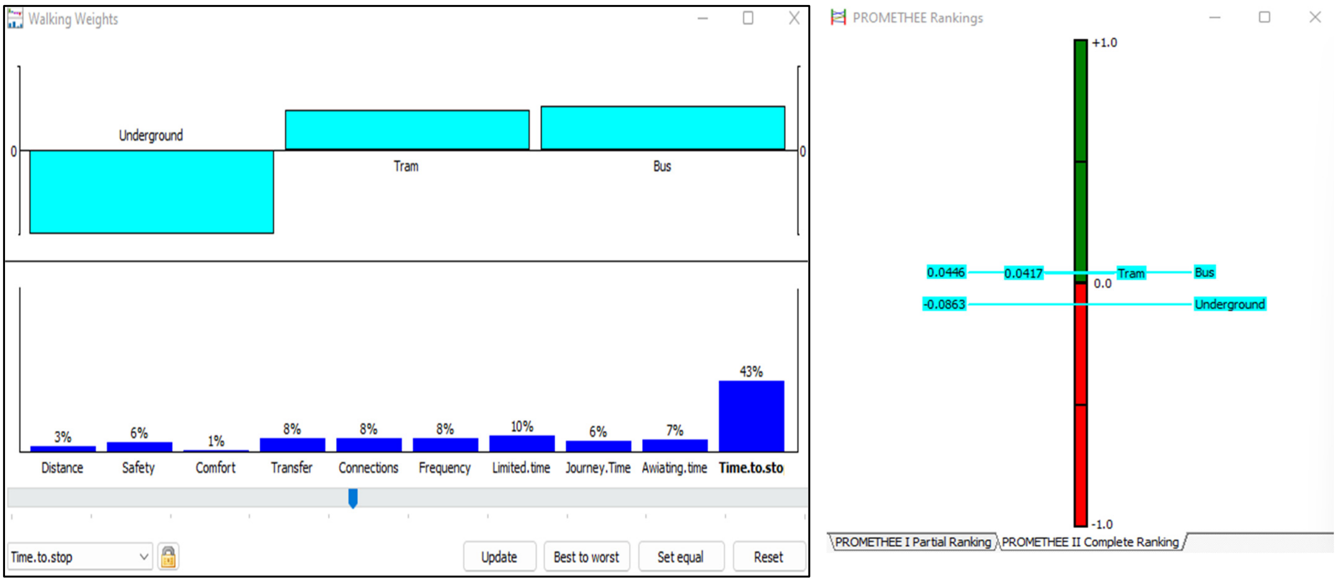
Criteria	Weight Stability Interval	Criteria	Weight Stability Interval
Distance to stop	[0.00%, 19.08%]	Frequency of lines	[0%, 100%]
Safety of stop	[0.65%, 100%]	Limited time of use	[0%, 100%]
Comfort in stop	[0%, 100%]	Journey time	[0%, 100%]
Need to transfer	[0%, 100%]	Awaiting time	[0%, 100%]
Fit connections	[0%, 100%]	Time to reach stop	[0%, 23%]

By changing the weight of the distance to stop to 41% Figure 5a the bus mode moves to the first position, followed by tram and underground modes in the third position, as seen in Figure 5b. Since the distance to stop is strongly linked to the time to reach stop, which is, in turn, very well assessed for bus mode, its weight is increased to 43% Figure 6a. The mode in question moves to the first position, as seen in Figure 6b.



(**a**) (**b**)

Figure 5. Sensitivity analysis 'Distance to stop', (**a**) criteria weights and (**b**) alternatives' rankings.



(**a**) (**b**)

Figure 6. Sensitivity analysis Time to reach stop, (**a**) criteria weights and (**b**) alternatives' rankings.

5. Discussion

The adopted approaches, AIJ-AHP-PROMETHEE and AIP-AHP-PROMETHEE, for evaluating public transport service quality have led to the same ranking of alternatives, indicating the vital importance in the final results of the underground mode, which was ranked in the first position in both models. Evaluators considered it as an optimum alternative according to service quality elements, it has good performance in the safety of stop, comfort in stop, frequency of lines, and journey time. However, the distance to stop and time to reach stop have a negative impact on its overall evaluation; likewise, the weights assigned to these criteria are weak compared to other attributes. The tram mode is ranked second for both approaches, which implies the service provided and its contribution to public transportation. It has a very good assessment for the frequency of lines criterion, which has significant weight importance (0.108) compared to other criteria. Bus mode is ranked third, as the worst alternative in the overall evaluation, but has a good assessment of the distance to stop and time to reach stop, which is evident because of the adopted strategy by policymakers. Furthermore, bus stations do not require extra investment as is the case with the other two modes. However, this can result in negative externalities on traffic such as congestion because of multiple bus stops that lead to long travel times, impacting service reliability [59,60]. In order to increase bus ridership, the government and policymakers should expand the quality of other criteria such as the comfort in stop and safety of stop, journey time, and frequency of lines.

Figure 7 explains the inevitable comparison between the first approach adopting the aggregation of individual priorities (AIP) by the calculation of the arithmetic mean of 100 computed net flows, and the second one for the aggregation of individual judgements (AIJ). The decision axis is in the same direction and forms a 45° angle with both approaches' axes. Underground mode is placed on the same side as the decision axis, bus mode is in the opposite direction, while tram mode is in the middle.

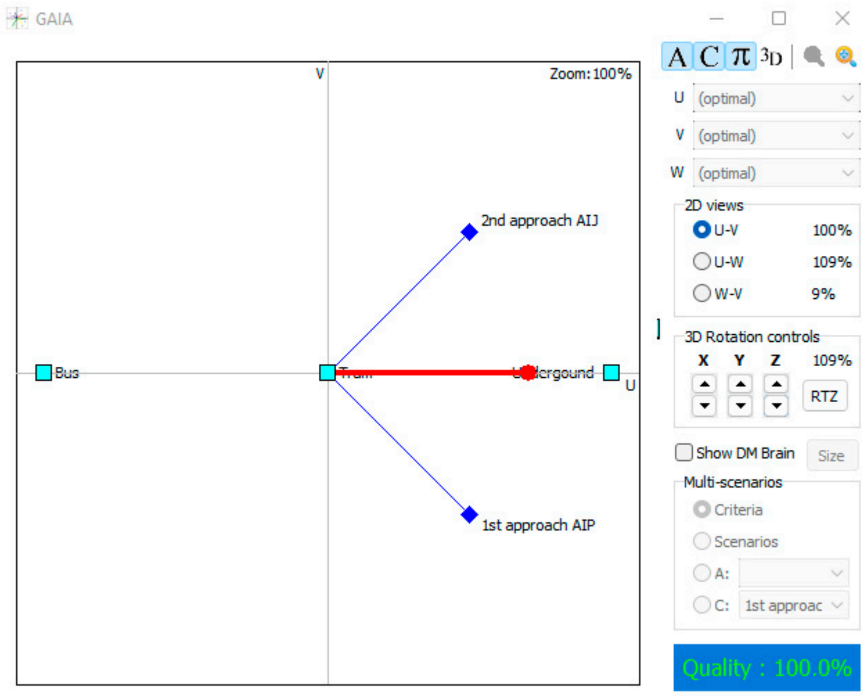


Figure 7. AIJ and AIP GAIA plane comparison.

With the aim to verify the results' efficiency of both approaches, we calculated the net flow ratio Table 9. The underground mode has very close values for both approaches, while in the case of the bus mode, both net flows ratios are superior to 0.75. This explains the strong agreement between these two methods, and the results for the introduced method are verified. However, the tram mode has a low ratio reaching 0.26 even though it kept the same ranking.

Table 9. Net flow ratio.

	AIP Approach	AIJ Approach	Net Flow Ratio
Bus	−0.16765	−0.2205	0.760317
Tram	0.017306	0.066	0.262212
Underground	0.150339	0.1545	0.973068

The presented case study has demonstrated the effectiveness of t AIJ–AHP–PROMETHEE method in the evaluation of public transport service quality. This consensual model's outcomes are aligned with existing research in terms of stressing the importance of key factor criteria in public transport mode choice, such as travel time and the frequency of lines [25,61,62]. This research deployed different approaches. Furthermore, the adopted model presented advantages in the aggregation of group evaluations in less time and effort compared to other approaches such as the AIP model, which can support policymakers to exploit and analyze evaluators' preferences. In particular, the use of the model's cardinal outputs (GAIA plane) and sensitivity analysis helps to visualize interactions between attributes and point out the optimal actions [63].

6. Conclusions

In this study, we constructed a novel model for an AIJ-AHP-PROMETHEE evaluation that is based on the aggregation of individual judgements. For the purpose of evaluating its efficiency, it has been compared with an existing approach that was presented in [18]. The final alternatives' ranking is similar, and both approaches have a strong agreement. The aggregation of the individual judgement approach reduces the procedure's time and efforts, instead of computing the final scores of AHP method and positive flows φ^{+}, negative flows φ^{-}, and net flows Φ of PROMETHEE I and II for every evaluator and calculating the arithmetic mean of computed flow. We introduced an integrated approach, aggregating individual judgements of AHP and PROMETHEE, which is strongly recommended in the case of a homogenous group of decision-makers that act as one person aiming for the same objective (i.e., university students). The geometric mean was used to calculate the values referring to the opinion of evaluators for pairwise comparison matrices. However, the aggregation of PROMETHEE indifference thresholds was reached with the arithmetic mean. The procedure has been executed only once, reducing calculations and analysis time, instead of the multiple calculations for the AIP model that depend on the number of evaluators. In this case study, the procedure was repeated 100 times for the AIP approach. The AIJ-AHP-PROMETHEE approach demonstrates a great advantage in analyzing a global evaluation from a cardinal perspective, and it is possible to examine the interaction between criteria and alternatives in the GAIA plane for the overall evaluation, while the weight stability intervals and sensitivity analysis enlighten sensitive criteria that are able to change final results. Nevertheless, these strong points are not able to be achieved with the conventional AIP approach that focuses on aggregating individual values. To the best of our knowledge, this is the first study introducing the AIJ-AHP-PROMETHEE model for homogeneous groups applied to real data from a large-scale group PROMETHEE in the public transportation field.

This study targeted the application of AIJ in the PROMETHEE method, and to the best of our knowledge, AIJ and AIP have only been applied for the AHP method, whereas here, only AIP was applied for PROMETHEE and we chose a homogeneous group of decision-makers (university students) to assess the effectiveness of the AIJ approach for the AHP-PROMETHEE model. The reason behind our choice comes from the significant percentage of public transport users that are from this category, which shapes the behavior of society toward public transport. However, in our future research, we strongly aim to include the opinion of other categories and involve experts in the evaluation procedure to assess mode choice preferences from different perspectives, which may or not influence the overall evaluation. We also suggest collecting data in the same city for different MCDM model analyses and comparing the outcomes with the introduced results. The limitations of this study can be seen in the number of alternatives, which only totaled three elements. It is also important to mention that the approach has to be applied to evaluate more alternatives (a number greater than 3) to be compared with the conventional method to determine its efficiency, as well as testing the ranking agreement between both approaches for multiple alternatives. The achieved results are promising, and we encourage the application of these approaches in other studies.

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S.D.; visualization. L.O.; supervision. S.D. All authors have read and agreed to the published version of the manuscript.

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