Oubahman *et al.*
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Analyzing university students' mode choice preferences by using a hybrid AHP group-PROMETHEE model: evidence from Budapest city

Laila Oubahman[1*], Szabolcs Duleba[1,2] and Domokos Esztergár-Kiss[1]

Abstract

Over the last decades, the analysis of mode choice preferences has become a vital aspect of enhancing the quality of public transport services. Most papers aim to derive conclusions from large-scale surveys. However, for specific homogenous patterns, such as university students, a smaller group of evaluators might also be sufficient. Such a survey can rather be considered as an expert survey, in which few representatives might express the preference of a larger community, thus, a different methodology can be more effective than the traditional statistical techniques. This paper aims to introduce a new approach that combines two multi-criteria decision-making methods, the analytic hierarchy process and the preference ranking organization method for enrichment evaluation, for a hybrid consensual model by aggregating the individual priorities defined by each decision-maker. The introduced model presents advantages in terms of reducing time, cost, and effort compared to statistical methods and requires solely necessary information from the users via objective and subjective evaluations. The model's effectiveness is tested with real-world data from the city of Budapest; highlighting the significant impact of the underground mode on users' behavior toward public transport. In addition, the outcomes are compared to other existing results of student preference surveys.

Keywords Mode choice, Group-PROMETHEE, AHP, Public transport, University students

1 Introduction

Surveying mode choice preferences is essential to support policymakers in forecasting the demand and elaborating various strategies. However, the representativity of collected data reflecting the behavior of the global community is necessary to validate the results [1]. Several large sample surveys have been conducted recently, normally, thousands of respondents are sufficient to complete the representativity criterion, but such a huge number of responses is very costly and difficult to acquire. In most cases, the duration of the survey is long, and the financing of the procedure is difficult [2]. The pattern of total users is generally too costly to survey, consequently, decision-makers turn to smaller and more representative groups as participators [3, 4]. In this paper, we analyze travel mode choices for a specific group (University students) as they present a significant ratio of the total users and are assumed to use various modes once compared to other patterns [5, 6]. Moreover, university students are trip generators shaping the behavior of the micro-society, which can be expanded to other patterns as well [7, 8].

*Correspondence:
Laila Oubahman
Laila.oubahman@edu.bme.hu
[1] Department of Transport Technology and Economics, Faculty of Transportation and Vehicle Engineering, Budapest University of Technology and Economics, Műegyetem Rkp. 3., Budapest 1111, Hungary
[2] Institute of Mathematics and Informatics, University of Nyíregyháza, Sóstói U.31/B., Nyíregyháza 4400, Hungary

Mode choice motivations are largely deployed in literature by adopting different approaches, it is influenced by several factors; such as environmental, psychological, and socio-demographical variables [9, 10]. Multi-criteria decision making (MCDM) methods present potential benefits in investigating mode choice and creating fundamental strategies [11]. As an example, mode choice in the city of Krakow is analyzed by the ELECTRE and the analytic hierarchy process (AHP) methods, where the community expresses the preference for the tram mode that was evaluated as reliable and secure with minimized travel time compared to the bus mode [12]. So far, the preference ranking organization method for enrichment evaluation (PROMETHEE) method has not been extensively introduced for public transportation mode choice [13]. Thus, the aim of this paper is to construct an integrated model for group mode choice preferences for a specific group (university students), by combining the AHP method with a specific version of the PROMETHEE method; the Group-PROMETHEE method, using a two-level hierarchy structure for a consensual MCDM model.

The well-established AHP method is applied to strengthen the model via pairwise comparisons, thus, defining the criteria's weights with respect to 9-point Saaty's scale for a two-level hierarchical structure [14]. The Group-PROMETHEE method introduced in the research [15] presents a great advantage in solving decision-making problems and prioritizing alternatives [16]. The Group-PROMETHEE method aims to aggregate the individual priorities expressed as final net flows Φ computed for each decision-maker. To investigate mode choice preferences by using the AHP Group-PROMETHEE model, university students are asked to express their mode choice preferences specifically for the available public transportation modes in Budapest; underground, tram, and bus modes based on a service quality hierarchical structure [17].

This paper makes an attempt to explore the problem of how to apply the AHP Group-PROMETHEE model to public transport mode choice. Furthermore, it relies on users' evaluations via a comprehensive survey and compares the results with existing results from the literature to highlight the effectiveness of the constructed approach in analyzing mode choice preferences taking into consideration tangible and intangible variables.

In the following sections, first, the scientific background for mode choice and the MCDM contributions are overviewed, which is followed by a detailed description of the applied methods (the AHP and the PROMETHEE). Afterward, the results and the discussion of the AHP Group-PROMETHEE model for mode choice preferences as a case study of Budapest are demonstrated, and conclusions are highlighted in the last section.

2 Literature review

Public transport stakeholders target promoting public and sustainable transport modes to reduce the negative externalities including congestion, noise, fuel consumption, and pollution with reference to mode choice analysis findings that highlight the factors influencing user behavior [18–21]. University students tend to shape future transport demand in the urban perimeter; hence, their preferences should be considered by policy-makers [22, 23]. A study focusing on students' behavior in Thailand concludes that car ownership is a major element, which influences university students' mode choice. According to the gender classification, 67.5% of the female respondents express their willingness to drive instead of using their bicycles because of safety issues and the lack of cycling infrastructure. On the other hand, only 57% of the male participants express the same preferences [6]. Thus, the adequate quality of cycling lanes and walking facilities may increase active commuting. By focusing on the safety, the physical environment, the psychological variables, the attractiveness of shared and non-motorized transport modes might be raised among commuters of universities [24, 25]. Furthermore, the research [26] points out the importance of making partnerships with universities to influence students' behavior toward all kinds of transportation modes in the United States. Management policy can be also effective in reducing the parking size and helps to change the mode choice, as in the case of Trieste University, where students in Italy are in favor of public transportation, thus there is a chance of increasing bus ridership [27].

The subjective feeling of safety, travel time, awaiting time at the station, and journey cost are the attributes discussed in previous research for identifying users' mode choices and expanding the use of public transport modes [28]. Remarkably, people seem to be more attached to private mode because of the independence, freedom, and superiority it provides as it is recognized as more than just a mean of transport [29]. For competing these advantages, it is vital to shorten the gap between the perceived and the desired service by exploring the motivations behind the use of private modes [30–32] and by involving users in the development of new strategies to regain their trust in public transport networks [33]. The indicator of public transport success is measured by the ability to attract a high number of passengers and to meet their preferences to understand their mode choice objectively and psychologically [34]. A study about German and Swiss communities highlights the psychological rail factor in mode choice; 75% of the survey participants prefer the tram in Swiss, while only 25% out of the 515 respondents prefer the bus. However, in the case of the German community, 63% of the evaluators choose the tram with reference to the frequency of the lines, the reliability, the comfort, and the additional positive feeling [35]. The same attributes are important for the Dutch community, as well. While the authors of the research [36] conclude that travelers have clear preferences for the tram compared to the bus because of the comfort, travel time, travel information, and frequency associated with this mode.

Similarly, for the same aim of evaluating public transport networks, MCDM methods are well-placed to analyze and solve multi-decision-making problems [37, 38]. The authors of the research [39] constructed a hybrid fuzzy AHP-TOPSIS model to evaluate customer satisfaction toward public transport service quality in the city of Istanbul. The results present that traffic congestion, air pollution, and energy consumption problems could be solved only if the stakeholders improve the quality of the provided service. For instance in the research [17], the AHP method is applied to determine the critical elements in a hierarchical supply quality structure, thus, helping the decision-makers in creating new strategies. Furthermore, the authors of the reference [40] highlights the most influential attributes in passengers' decisions through the evaluation of passenger demand in the city of Amman by using the AHP method and taking both the supply quality model and the fares into consideration. Although, the research [41] introduces the Grey-AHP model for improving the quality of the transport service, thus attaining sustainable developments from the perspective of a specific group of passengers. Sustainable public transport solutions are also efficient to construct strategies accepted by the community as it is introduced in [42] that spotlight the technical, social, and political aspects of the same model.

In the same context, involving specific evaluators in the same model has to be also analyzed. The Group-PROMETHEE decision support system enables the aggregation of decision-makers' opinions [43]. The authors of the research [15] construct a global decision support system to encourage decision-makers to reach a compromise. This approach is beneficial to evaluate the preferences of a group of decision-makers. However, to achieve logical and worthy results with this method, commitment and time are required from the evaluators' side. Furthermore, the reference [44] utilizes the Group-PROMETHEE method and promotes behavioral decision-making based on heterogeneous information. The divergence and the vagueness of the group evaluation could be managed with fuzzy PROMETHEE to avoid the uncertainty generated by various decision-makers [45, 46]. Moreover, PROMETHEE is a powerful method that handles diverge information via transparent calculations and ensures the quality of the group decision-making process [47]. PROMETHEE has a unique characteristic compared to any other MCDM methodology, this feature is the application of real physical parameters for thresholds and evaluation scale, i.e., instead of using the general Likert-scale only, the PROMETHEE enables to specify objective measures like distance and time. This makes the decision-making process less subjective and more trustworthy.

Overall, it is demonstrated that the AHP Group-PROMETHEE model has not been used to investigate public transport mode choice, specifically among university students. This study endeavors to examine the effectiveness of the constructed model in analyzing group mode choice preferences. The Group-PROMETHEE model is applied to real data for Budapest city, which is characterized by a variety of public transport modes (tram, underground mode, bus), that create a competitive aspect seeking the attraction of loyal users [48].

3 Method

The MCDM is applied to solve complex problems in different domains because of the wide range of techniques it provides. The approach adopted in this paper combines two well-known methods in MCDM (the AHP and the PROMETHEE), which are simple to apply and require only a few necessary information from the evaluators and decision-makers. The AHP method is used to assign weights to criteria through pairwise comparison, and the PROMETHEE method is applied for outranking alternatives. In the evaluations, the efficiency of the Group-PROMETHEE approach is demonstrated via the aggregation of individual priorities by utilizing the arithmetic mean of the net flows computed.

3.1 The AHP method

AHP method is one of the most-used MCDM methods, because of its ability to solve complex problems [37]. The initial step of the AHP method is constructing the hierarchical decision tree that links the top-level elements, the objective of the evaluation, which are also connected to detailed levels called leaves. The elaboration of the pairwise comparison matrices is made for each level separately with the aim to be assessed by the decision-makers. The matrix eigenvector for the pairwise comparison is calculated as shown in Eqs. (1) and (2):

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

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

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

After data collection from the evaluators, a consistency check might be crucial in case, there are non-expert decision-makers [49]. Values should be positive, reciprocal, and transitive. The following conditions should be verified, Eqs. (3) and (4):

$$\text{Reciprocity condition}: a_{ij} = \frac{1}{a_{ji}} \quad \forall \quad i,j \in \{1, \ldots n\} \tag{3}$$

$$\text{Transitive condition}: a_{ij} = a_{ik} * a_{kj} \quad \forall \quad i,j,k \in \{1, \ldots n\} \tag{4}$$

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

The transitive condition is not perfectly fulfilled in the experiential matrices [50]. Thus, the consistency ratio is computed to verify matrices consistency by using Saaty's eigenvector method [14] (Table 1).

The consistency index (CI) is calculated by using Eq. (5):

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{5}$$

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

Random index (RI) is a random value provided by [14], and it depends on the size of the matrix. Table 2 shows different values of RI in the function of the size.

The consistency ratio is accepted if and only if CR < 0.1 [51] and can be computed as follows:

$$CR = \frac{CI}{RI} \tag{6}$$

Table 1 Judgment scale of relative importance for pairwise comparisons [14]

Numerical values	Verbal descriptions
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

Final weights considering the hierarchical structure between the upper level and its elements is calculated as explained in Eq. (7).

$$w_{Ai} = \frac{w_j}{\sum_{j=1}^{m} w_j} \cdot \frac{w_{ij}}{\sum_{k=1}^{n} w_{ik}} \tag{7}$$

where w_j is the weight of the previous level, $\sum_{j=1}^{m} wj$ is the sum of the weights at the previous level, $j = (1, \ldots m)$ is the number of the elements at the previous level, w_{ij} is the computed eigenvector at the current level, $\sum_{k=1}^{n} w_{ik}$ is the sum of the weights at the current level, $k = (1, \ldots n)$ is the number of the elements at the current level, and w_{Ai} is the new score calculated for the current level with $i = 1, 2, \ldots, n$.

The aggregation of AHP evaluations can be made by using different approaches. To aggregate the individual judgements, the geometric mean is advisable because it avoids rank reversals [51]. For the aggregation of the individual priorities, Eq. (8) is adopted.

$$f(w_1, \ldots w_k) = \sqrt[k]{\prod_{j=1}^{k} w_j} \tag{8}$$

where $(w_1, w_2, \ldots, w_k)$ denotes entries in the same matrix position, k is the number of evaluators participating in the study.

3.2 The PROMETHEE method

The PROMETHEE method is an efficient procedure for the evaluation of alternatives. After defining the evaluating criteria, decision-makers determine whether the criteria have to be minimized or maximized. The purpose of the method is avoiding trade-offs in PROMETHEE I, and enriching the dominance within criteria and alternatives, as well as eliminating incomparability detected in PROMETHEE I and solved in PROMETHEE II. Six preference functions are defined to eliminate scale effects between criteria [52], decision-makers choose the type of the preference functions and the thresholds values depending on the criteria's characteristics. The utilized PROMETHEE preference functions in this study are Usual and Quasi-criterion functions and are explained in Eqs. (9)–(10).

Type I. Usual Criterion

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

Table 2 The RI from randomly generated matrices [14]

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

Type II. Quasi-criterion

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

After selecting preference functions, the calculation of the leaving flow φ^+, the entering flow φ^-, and the net flow Φ through PROMETHEE I and PROMETHEE II is the next step.

Considering a set of criteria $C = \{g_1, \ldots, g_m\}$ and a set of alternatives $A = \{a_1, \ldots, a_n\}$. The pairwise comparison and the amplitude of deviation d between two alternatives a_i and $a_{i\prime}$ with $\{i.i\prime\} \in \{1, \ldots, n\}$ and $i \neq i\prime$ for g_j criterion, $j = \{1, \ldots, m\}$, is calculated, as shown in Eq. (11):

$$d_j(a_i, a_{i\prime}) = g_j(a_i) - g_j(a_{i\prime}) \tag{11}$$

The preference value between two alternatives depends on the type of the criterion. In the case of maximized criterion, Eq. (12) is used otherwise Eq. (13).

$$P_j(a_i, a_{i\prime}) = F_j\left[d_j(a_i, a_{i\prime})\right] \tag{12}$$

$$P_j(a_i, a_{i\prime}) = F_j[-d_j(a_i, a_{i\prime})] \tag{13}$$

The value of the preference function is a positive number belonging to the interval [0.1].

$$0 \leq P(a_i, a_{i'}) \leq 1; \quad \forall a_i, a_{i'} \in A \tag{14}$$

3.2.1 The PROMETHEE I

The PROMETHEE I provides a partial ranking of the criteria without any loss of information. It calculates the leaving flow (positive flow) $\varphi^+(a_i)$, which assesses how alternative a_i outranks all other alternatives, and the entering flow (negative flow) $\varphi^-(a_i)$, which evaluates how other alternatives outrank alternative a_i. After assigning positive weights to m criteria $\{w_1, \ldots w_m\}$ with $\sum_{j=1}^{m} w_j = 1$, the comprehensive preference value π can be computed.

$$\text{For } \{a_i, a_{i\prime}\} \in A \quad \pi(a_i, a_{i\prime}) = \sum_{j=1}^{m} P_j(a_i, a_{i'}) * w_j \tag{15}$$

$$\text{The positive flow } \varphi^+ : \varphi^+(a_i) = \frac{1}{n-1} \sum_{a_{i\prime} \epsilon A - \{a_i\}} \pi(a_i, a_{i\prime}) \tag{16}$$

$$\text{The negative flow } \varphi^- : \varphi^-(a_i) = \frac{1}{n-1} \sum_{a_i \epsilon A - \{a_{i\prime}\}} \pi(a_{i\prime}, a_i) \tag{17}$$

The conclusion from the partial ranking of two alternatives can be a preference relation (P), an indifference relation (I), or incomparability (R). In every case, some conditions should be fulfilled.

$$\text{Preference(P)} : a_i P^I a_{i\prime} \begin{cases} \varphi^+(a_i) > \varphi^+(a_{i'}) \ and \ \varphi^-(a_i) < \varphi^-(a_{i'}) \ or \\ \varphi^+(a_i) > \varphi^+(a_{i'}) \ and \ \varphi^-(a_i) = \varphi^-(a_{i'}) \ or; \\ \varphi^+(a_i) = \varphi^+(a_{i'}) \ and \ \varphi^-(a_i) < \varphi^-(a_{i'}) \end{cases} \tag{18}$$

$$\text{Indifference (I)} : a_i I^I a_{i\prime} \quad \varphi^+(a_i) = \varphi^+(a_{i'}) \ and \ \varphi^-(a_i) = \varphi^-(a_{i'}) \tag{19}$$

$$\text{Incomparability (R)} : a_i R^I a_{i\prime} \begin{cases} \varphi^+(a_i) < \varphi^+(a_{i'}) \ and \ \varphi^-(a_i) > \varphi^-(a_{i'}) or; \\ \varphi^+(a_i) > \varphi^+(a_{i'}) \ and \ \varphi^-(a_i) < \varphi^-(a_{i'}) \end{cases} \tag{20}$$

3.2.2 The PROMETHEE II

The comprehensive ranking in PROMETHEE II eliminates the incomparability identified in PROMETHEE I, it is simply the subtraction of the entering flow φ^- from the leaving flow φ^+.

$$\Phi(a_i) = \varphi^+(a_i) - \varphi^-(a_i) \tag{21}$$

Alternative preference increases proportionally with the value of the net flow Φ which highlights solely two assumptions: preference and indifference.

$$\text{Preference(P)} : a_i P^{II} a_{i'} \quad \Phi(a_i) > \Phi(a_{i'}) \tag{22}$$

$$\text{Indifference(I)} : a_i I^{II} a_{i\prime} \quad \Phi(a_i) = \Phi(a_{i'}) \tag{23}$$

The amount of the entering flows is the same as the leaving flows. Thus, the sum of all comprehensive flows computed in a problem equals to 0 and $\Phi \in [-1, 1]$.

$$-1 \leq \Phi(a_i) \leq 1, \quad \forall a_i \in A \tag{24}$$

3.2.3 The AHP Group-PROMETHEE approach

In this study, two MCDM methods are combined (the AHP and the Group-PROMETHEE) to build an efficient decision-making model. Evaluators use pairwise comparison to assign weights to the criteria in a hierarchical structure by using Saaty's scale [14], thus computing the weight scores of the criteria. Regarding the PROMETHEE method, the first step includes determining the criteria to be maximized and the criteria to be minimized as well as defining the preference functions and required thresholds. It is worth noting that the same preference functions have to be used by all respondents.

Global evaluation of the alternatives vis-à-vis the criteria is calculated after determining the net flow (PROMETHEE II) computed for all evaluators. For reaching the global preference scores of a group of evaluators, mean-based calculations are the most popular techniques, e.g. weighted geometric mean method (AIP WGMM) or weighted arithmetic mean method (WAMM). Certainly, it causes the generalization of the individual preferences but still seems a suitable solution to characterize the preferences of a group [53–55]. Note that weighting the individual evaluators should only be done if the heterogeneity of the pattern is assumed and the deviations of weights are strongly justified (by significant differences in decision-making power or expertise). This is not the case in the current research. In the present study, we use the arithmetic mean as it is the most suitable method for aggregating the individual priorities of the PROMETHEE method because some alternatives might have null values for net flow, thus the geometric mean would annul the global score as well.

Thus, to calculate the global evaluation and to provide final alternatives outranking according to the aggregated evaluations, we use the formula explained in Eq. (25).

$$\Phi_G(a) = \frac{\sum_{h=1}^{k} \Phi_h(a)}{k} \quad (25)$$

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

Figure 1 summarizes the adopted methodology of this paper.

4 Results and discussion

The presented methodology is applied to analyze public transport mode choice by university students in Budapest with reference to the service quality hierarchical structure introduced in the research [17] and presented in Fig. 2. A comprehensive questionnaire is constructed to bring the voice of the users into the spotlight through four separate sections. The survey was conducted in November and December 2020. 48% of the samples were filled in by evaluators that were selected randomly inside the university halls, and 52% were filled in electronically by the evaluators. The average time required to fill out the questionnaire is 35 min. The first section includes the evaluators' general information. The second section is for the AHP pairwise comparison including five pairwise matrices in total: one matrix (5×5), two matrices (2×2),

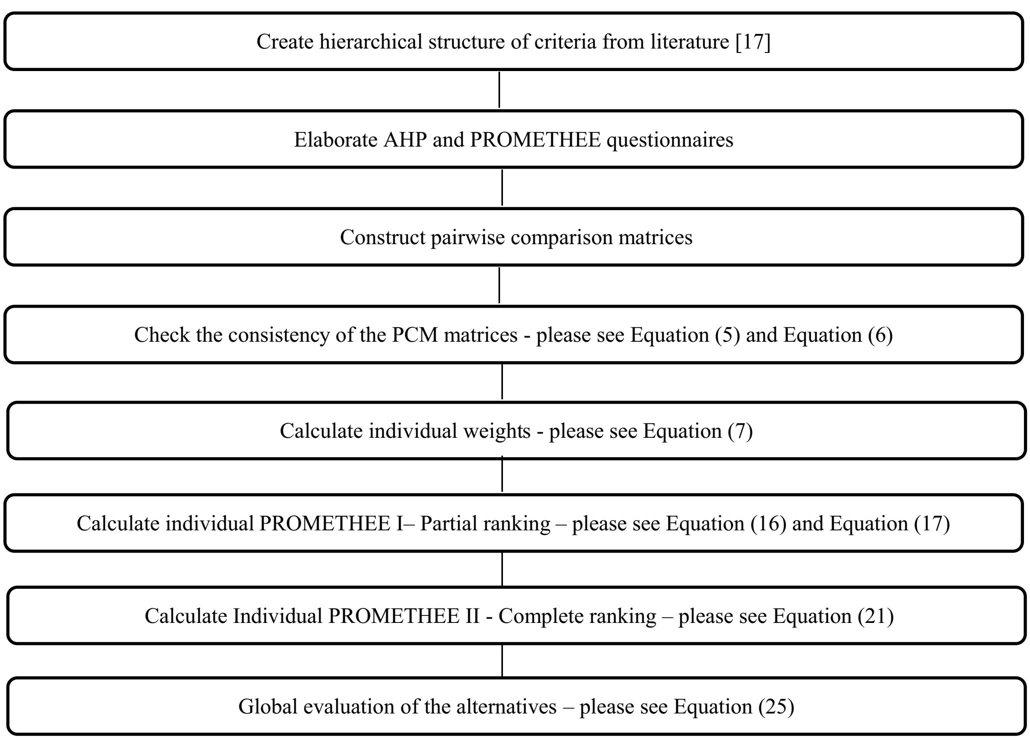

Fig. 1 The description of the utilized methodology

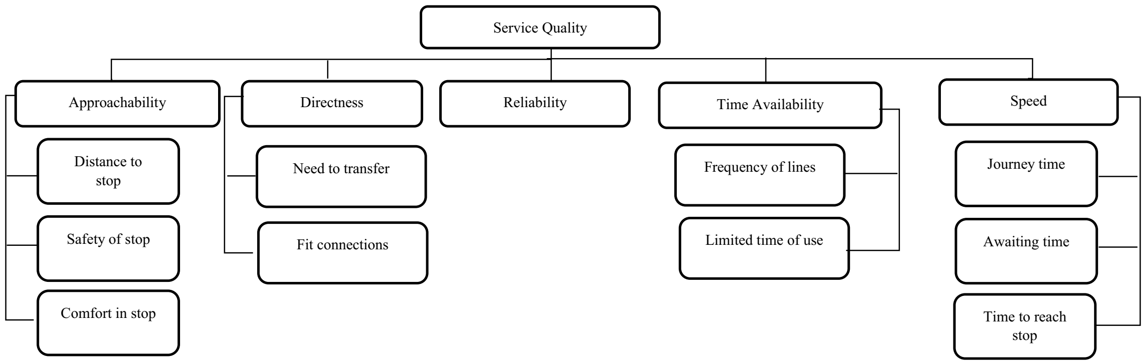

Fig. 2 Public transport service quality model [17]

and two matrices (3×3). The third section assesses the objective and subjective values for PROMETHEE by considering the detailed level of the structure, while the last one concerns the socio-demographical characteristics. The survey aims to investigate public transport mode choice from the perspective of university students as there is a significant usage rate of public transportation by this group of people. 100 evaluations are collected out of 144.539, which is the total number of students at Budapest's universities. Statistically, the number of samples is not representative, but the MCDM approach provides a profound perception of the study based on pairwise comparisons better than a simple survey [14]. This approach is relevant in the current research, where the most important characteristics of the pattern and the total community are identical. A detailed description of the surveyed pattern is presented in Table 3.

4.1 The application of the AHP method

In this study, the AHP method is applied to compare the criteria forming a hierarchical structure of two levels including the most significant attributes of the public transport service's quality [17]. At the first level, there are five criteria to compare: approachability, directness, time availability, speed, and reliability. On the other hand, at the second level, ten criteria are evaluated: distance to stop, safety of stop, comfort in stop, need to transfer, fit connections, frequency of lines, limited time of use, journey time, awaiting time, and time to reach stop. The hierarchical structure of service quality is presented in Fig. 2, and the characteristics of the attributes can be seen in Table 4.

Note that hierarchical connections (set-subset relations) are much stronger in this criteria structure than non-hierarchical ones. Certainly, as in most criteria

Table 3 The characteristics of the surveyed pattern

Category	Sub-category	The share (%)
Gender	Female	51
	Male	49
Surveyed universities	BME (Budapesti Műszaki egyetem)	35
	ELTE (Eötvös Loránd Tudomány Egyetem)	27
	Other universities	38
Academic level	Bachelor	53
	Master	38
	Ph.D	9
Age	18–25	77
	26–40	22
	Above 41	1
Ticket's type	Monthly pass	89
	Single ticket	3
	Standard monthly pass	8

Table 4 The interpretation of service quality attributes

Criteria	Preference function	Min–Max	Measure	Interpretations
Service quality	–	–	–	–
Approachability	–	–	–	Line access
Directness	–	–	–	The ability to reach the destination without changing vehicles
Reliability	–	–	–	Respecting planned schedules
Time availability	–	–	–	The time frame of lines from the first line of the day up to the last of the day
Speed	–	–	–	The speed of traveling process
Distance to stop	Quasi-criterion	Minimized	Meters	The proximity of the origin stations
Safety of stop	Usual Criterion	Maximized	Likert scale	Subjective feeling
Comfort in stop	Usual Criterion	Maximized	Likert scale	Seats, cooling system, heating system
Need to transfer	Quasi-criterion	Minimized	Number of vehicle changes	The need to change the vehicle to reach the destination
Fit connection	Quasi-criterion	Minimized	Minutes	The time connection between the lines to reach the destination
Frequency of lines	Quasi-criterion	Minimized	Minutes	The frequency of the bus, tram, and underground modes
Limited time of use	Quasi-criterion	Maximized	Hours	The time between the first and the last line of a day
Journey time	Quasi-criterion	Minimized	Minutes	The time between the on-board and getting-off from the vehicle
Awaiting time	Quasi-criterion	Minimized	Minutes	Waiting time at the station for the line
Time to reach stop	Quasi-criterion	Minimized	Minutes	The necessary time to reach the origin station

models, some overlaps exist among the attributes, but the connection is not deterministic, while the set-subset relation is. For instance, in the case of the distance to stop and time to reach stop, in which these two criteria are somewhat correlated, but they are not determining each other. On one hand, with the existence of multiple traffic lights in the road leading to the initial bus stop, the reaching time might be higher than the same distance without any traffic lights. Additionally, considering up-hill and down-hill (e.g., public bus transport in San Francisco), the time to get to the stop might be higher or lower for a pedestrian or a biker and the distance is the same.

The evaluators make a comparison between every two criteria from the same hierarchical level and branch based on Saaty's judgement scale (Table 1). 18 evaluations are made by each decision-maker from one (5×5) matrix, two (2×2) matrices, and two (3×3) matrices.

The consistency of the matrices is verified according to the defined RI index in Table 2, where the evaluations are considered separately for every decision-maker. Thus, 100 sets of local and final weights are used for the individual PROMETHEE weight values. To assess the criteria with a high impact on mode choice for this pattern, the aggregation of the individual priorities for the AHP weights is conducted by using the geometric mean formula explained in Eq. (8). As it is shown in Table 5, the first-level criteria make an impact on the local ranking of the second-level criteria. Time availability and speed

Table 5 The local and final weights for service quality criteria

First-level criteria	Weights	Rankings	Second-level criteria	Local weights	Local rankings	Final weights	Final rankings
Approachability	0.109	5	Distance to stop	0.281	7	0.030	9
			Safety of stop	0.516	1	0.055	6
			Comfort in stop	0.101	10	0.011	10
Directness	0.168	3	Need to transfer	0.415	4	0.071	4
			Fit connections	0.431	3	0.072	3
Time availability	0.242	1	Frequency of lines	0.373	5	0.091	2
			Limited time of use	0.441	2	0.109	1
Speed	0.199	2	Journey time	0.306	6	0.061	5
			Awaiting time	0.241	9	0.048	8
			Time to reach stop	0.255	8	0.051	7
Reliability	0.124	4					

are considered the most important criteria for the first level. These two criteria are followed by directness, reliability, and approachability. The safety of the stop at the second level is evaluated as a crucial element for the participants, which is followed by the limited time of use and fit connections. Awaiting time and comfort in stop are in the ninth and tenth positions, respectively showing less impact on the mode choice. However, this ranking changes because of the first-level criteria scores, where the limited time of use and frequency of lines get the first and second positions, respectively because of the time availability's weight. The score of the speed criterion brings one gained position for its sub-elements. Thus, journey time, awaiting time, and time to reach the stop come from the sixth, ninth, and eighth positions to the fifth, eighth, and seventh positions, respectively. Safety of stop loses its importance, thus earning the sixth position instead of the first since the approachability is ranked to the fifth position within the first-level criteria. The same applies to the distance to stop criterion, which drops two positions from the seventh to the ninth. Comfort in stop, need to transfer, and fit connections keep the same ranking values.

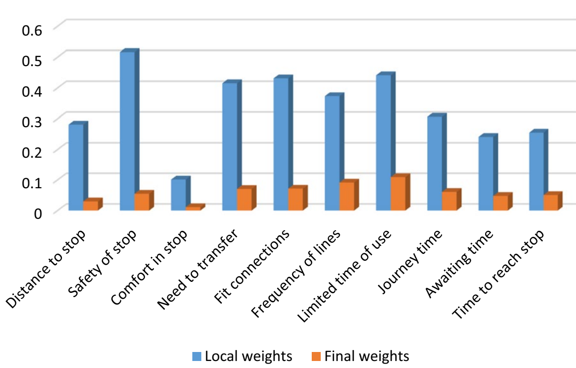

Fig. 3 Local and final weights of the criteria

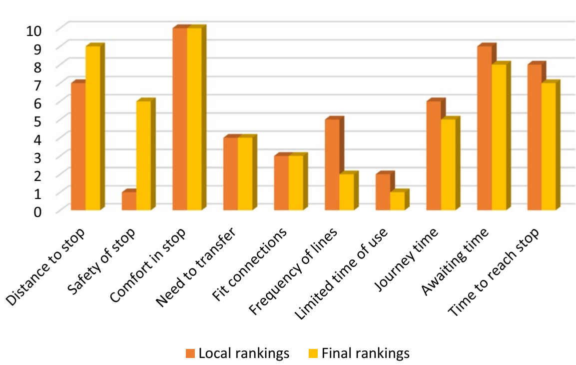

Fig. 4 Local and final ranking of the criteria

In conclusion, the computed evaluations in Table 5 reveal the high importance of limited time of use, frequency of lines, fit connections, need to transfer, and journey time. However, distance to stop and comfort in stop are ranked in the last positions with less importance from the perspective of the university students' pattern. Please see Figs. 3 and 4.

4.2 The application of the Group-PROMETHEE

Similar to the previous method, in this phase, the evaluations are considered separately. For each respondent, the AHP final scores are used individually for the PROMETHEE weight assignment. Afterward, 100 sets of partial ranking (PROMETHEE I) and complete ranking (PROMETHEE II) are calculated. Please see an example of PROMETHEE evaluation in Table 6. It is worth mentioning that the evaluating criteria in the PROMETHEE stage are the second-level criteria from the hierarchical structure.

To calculate PROMETHEE flows, the same procedure is followed for all evaluations. The global evaluation is the arithmetic mean of the computed flows in partial and complete ranking [15].

According to 100 evaluators as shown in Table 7, the global partial ranking (PROMETHEE I) of public transport modes considers underground mode as the optimum transportation mode based on the entering and leaving flow values. It is followed by the tram and then bus mode.

The global comprehensive evaluation (PROMETHEE II) results the same ranking as the partial ranking.

$$\Phi_G(Underground\ mode) > \Phi_G(Tram) > \Phi_G(Bus) \tag{26}$$

To stress out the important data collected from the respondents that support the final ranking, we emphasize that the stated awaiting time at the station for underground mode is less than five minutes for all the participants, which is the maximum indicated threshold value, as well. As for the frequency of lines, it tends to be less than five minutes for all evaluators demonstrating good frequency and increasing the reliability of this mode [56]. On the other hand, the assessed awaiting time for the tram mode is indicated as less than five minutes by 96% of the respondents, while it is only 62% for the bus mode. The results explain the huge influence of service quality attributes on mode choice with the AHP Group-PROMETHEE approach, the computation of the global positive and negative flows with PROMETHEE I partial ranking leads to the same ranking as the global complete ranking with PROMETHEE II. The vital importance of the underground mode, which is ranked in the first position and estimated as the optimum alternative

Table 6 Example of PROMETHEE method entries

	Distance to stop	Safety of stop	Comfort in stop	Need to transfer	Fit connection	Frequency of lines	Limited time of use	Journey time	Awaiting time	Time to reach stop
Unit	Meters	Likert scale	Likert scale	Number	Minutes	Minutes	Hours	Minutes	Minutes	Minutes
Max/Min	Min	Max	Max	Min	Min	Min	Max	Min	Min	Min
Weight	0.03	0.04	0.02	0.21	0.03	0.06	0.41	0.04	0.03	0.06
Preference function	Quasi-criterion	Usual	Usual	Quasi-criterion	Quasi-criterion	Quasi-criterion	Quasi-criterion	Quasi-criterion	Quasi-criterion	Quasi-criterion
Thresholds	300	–	–	0	5	4	1	5	5	5
Alternatives										
Bus	650	Average	Very bad	0	0	10	24	31	3	9
Tram	300	Average	Average	1	7	3	20	25	1	4
Undergro-und	1500	Good	Good	0	0	3	20	5	1	15

Table 7 Group-PROMETHEE partial and complete ranking

AHP Group-PROMETHEE	φ_G^+	φ_G^-	Partial ranking	Φ_G	Complete ranking
Bus	0.085	0.252	3	−0.167	3
Tram	0.148	0.131	2	0.017	2
Underground	0.231	0.081	1	0.150	1

with great impact on the public transport mode choice, is demonstrated. Whereas, the tram mode is ranked at the second position, which implies that it could be a promising option that may increase the ridership of public transport. Finally, because of the quality of the provided service, the bus mode is in the third position as the least preferred mode to use by the respondents.

This model highlights the same conclusions in terms of mode choice preferences, as the case of university students in Qatar; that justify their mode choice depending on the cleanliness, the safety, the travel time, and the frequency of the bus lines [57]. While Brazilian university students express the impact of comfort and safety as the main criteria for transportation mode selection [56]. Moreover, a case study from the Czech Republic explains the correlation between the station's proximity, the frequency of lines, the connections between lines attributes, and the choice of adequate transportation mode [58]. In a case study presented in the research [59], the community of Budapest expresses the importance of travel time, time to reach stop, and reliability, which are ranked in the first three positions out of the service quality attributes. The findings of the current study are in line with previous research. The underground mode, which is in the first position, has a major overall assessment with great judgements regarding safety, comfort in stops, journey time, frequency of lines, and awaiting time. The preference of rail modes among travelers is justified by the comfort and the psychological factors, it is clearly stated and proved by the community of Krakow as well as German and Swiss communities [12, 35].

The great importance allocated to the underground mode by the users encourages the addition of new lines for new destinations, thus increasing the use of this mode. Tram mode is a favorable mode, which might lead potential users toward public transport. Nevertheless, the bus mode needs major intents to enhance its service quality and build new strategies to increase bus ridership, especially considering that it does not need such a huge investment for constructing stations and roads as in the case of the other two modes [60].

5 Conclusion

In this study, the elements of the adopted models are complementary and strengthen the weaknesses of each method specifically in defining the weights of the criteria by using a logical approach approved in the literature. The AHP method simplifies the calculations of the weights following methodological reasoning for a hierarchical structure. Moreover, the PROMETHEE method brings detailed visibility about mode choice based on the preferences of the criteria from AHP results and its own entries; including the defined thresholds and the preference functions to outrank three different transport modes by examining both objective and subjective data. Altogether, the AHP Group-PROMETHEE proves the strengths of combining two well-known MCDM methods to serve policy-makers in constructing new strategies, focusing on the preferred criteria, and at the same time, projecting these preferences on the existing modes to identify the ones with adequate service quality and others with weaknesses to improve.

The adopted AHP Group-PROMETHEE model for investigating public transport mode choice demonstrates a great advantage in supporting decision makers to analyze the population's preferences with less effort in collecting samples, reducing the cost and the time of the research compared to the traditional statistical approaches. With only a small number of samples for homogeneous groups, MCDM methods ensure a deep understanding of the collected data. The AHP Group-PROMETHEE method requires necessary information from the decision-makers and understandable data. The model is empowered by using the AHP method to determine the final weights for a hierarchical service quality structure and to rank the criteria according to their importance from the perspective of university students. The evaluations express the preference of the limited time of use, frequency of lines, fit connections, and need to transfer besides journey time that gained one position ranking, because of the influence of its sub-element criterion (speed) which is ranked to the second position following time availability attribute at the first level. This ranking presents the importance of the consideration of the speed factor and its impact on mode selection. Nevertheless, comfort in the stop and distance to the stop do not get a serious concern once compared to the other service quality attributes.

It can be stated that the limitations of this proposed model are manifested in the demonstration of the interactions between the criteria and the alternatives because of the net flows' aggregation, which leads to information loss. To overcome this drawback, studying the mutual interactions between the criteria may bring great analysis interpretation via the integration of the G-PROMETHEE method with the Choquet Integral [61]. For further research, deploying the Group-PROMETHEE method to investigate public transport mode choice is recommended since it brings such new benefits as reducing the time and the cost of the survey process. For trustworthy results, extending the method with other applications for mode choice will reinforce the effectiveness of the Group-PROMETHEE mode choice as a pillar of MCDM methods, and support policymakers in adopting efficient strategies.

Author contributions

LO and SD conceptualized the research and created the suitable methodology. LO conducted the survey and calculated the results. In paper writing all authors participated. The author(s) read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare no competing interests.

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