18th Euro Working Group on Transportation, EWGT 2015, 14-16 July 2015, Delft, The Netherlands

Multi-Criteria Appraisal of Multi-Modal Urban Public Transport Systems

Mehdi Keyvan-Ekbatani[a] *, Oded Cats[a]

[a] *Department of Transport and Planning, Faculty of Civil Enineering and Geosciences, Delft University of Technology, Delft, 2600 GA, The Netherlands*

Abstract

This study proposes a multi-criteria decision making (MCDM) modelling framework for the appraisal of multi-modal urban public transportation services. MCDM is commonly used to obtain choice alternatives that satisfy a range of performance indicators. The framework embraces both compensatory and non-compensatory approaches including lexicographic, Simple Additive Weighting (SAW), technique for order preference by similarity to the ideal solution (TOPSIS) and Concordance Analysis. These methods are applied on survey data collected through a questionnaire in Teheran, Iran. The survey encompassed passengers, operators and the wider community and inquired about the perceived attributes of three urban public transport modes: regular bus (RB), bus rapid transit (BRT) and rail rapid transit (RRT). The aforementioned MCDM techniques were applied to rank the performance of the three studied transit modes. The outputs of this study are instrumental in supporting planning decisions and prioritizing measures to improve public transport services.

Keywords: Urban Public Transport Systems; Multi-Criteria Decsion Making; Performance Evaluation

1. Introduction

Urban public transport is one of the most significant components in creating a sustainable urban environment. Attractive, accessible and reliable public transport systems can provide the basis for economically efficient and environmentally sustainable urban development. The development of such services could potentially be facilitated

* Corresponding author. Tel: +31 (15) 27 86302.
E-mail address: m.ekbatani@tudelft.nl

by the appraisal of existing public transportation services. Performance can be characterized by a wide range of perspectives including: efficiency, effectiveness, economic, social and environmental dimensions. Whilst a large range of indicators have been proposed and applied for assessing public transport services, it remains unknown how various service aspects could be integrated to provide a cohesive performance evaluation. Moreover, urban public transportation development and services have diverse impacts on users, operators and the community. The appraisal must therefore consider different affected groups, often defined as system users and non-users, or general public.

Service performance is conventionally measured by the relations between service inputs (cost), service outputs (supply) and service consumption (demand). The relation between cost and service outputs refers to cost-efficiency whereas the relation between service outputs and service consumption corresponds to service effectiveness. Finally, the service consumption obtained for a given cost is a cost-effectiveness indicator. Public transport service performance has been a subject of extensive interest due to its importance to planners, practitioners and benchmarking purposes (TCRP 1995, 2003). In the context of public transport systems, various indicators have been proposed to measure cost-efficiency, service-effectiveness and cost-effectiveness, such as fleet utilization, service reliability and cost per passenger, respectively (Vuchic 2004).

Service providers, planners and users have distinctive perceptions on system performance. Public transport operators are mostly concerned with cost efficiency. This is especially true where gross contracts are used in the procurement process. Cost efficiency implies a focus on fleet utilization indicators and minimizing the deviation from plans. In contrast, service users are most interested in service effectiveness aspects such as service availability in terms of coverage and frequency, service reliability and comfort. Public transport agencies are interested in maximizing cost effectiveness, ensuring that service inputs yield high levels of service consumption as measured in terms of ridership and public transport modal share. Cost effectiveness has also implications on the farebox recovery rate - the share of operational costs that are covered by ticket sales - and hence the required subsidy level (TCRP 2003).

Measuring and analyzing satisfaction with public transport services is essential for service performance monitoring, market analysis, benchmarking and the identification of priority areas. The determinants of service satisfaction have thus been a subject of extensive research. According to the gap analysis approach proposed in TCRP (1999), passengers' satisfaction refers to the gap between expected and perceived service. Stradling et al. (2007) found that non-instrumental variables such as cleanliness, privacy, safety, convenience, stress, social interaction and scenery play a significant role in influencing traveller satisfaction with their journey. Based on a survey in eight European cities, Susilo and Cats (2014) found that different user groups have distinctive determinants of satisfaction with trip stages for various travel modes with station environment, on-board comfort and ease-of-transfer among the most important determinants. A time series dataset from Sweden enabled Cats et al. (2015) to analyze how determinants of travel satisfaction changed over thirteen years. They concluded that customer interface, travel safety, trip length, reliability of operations and staff and assistance were consistently among the most important determinants of travel satisfaction.

The need to measure and assess public transport service performance has led to the development of an abundant number of quantitative indicators. A multi-criteria analysis is commonly used in project appraisal in order to account for multiple aspects and perspectives. Keyvan-Ekbatani and Vaziri (2012) suggested that any appraisal of public transport services must take into consideration the inherent complexity of stakeholders perspectives. While Macharis et al. (2009) assert that a non-compensatory multi-criteria method is useful in including different stakeholders' perspectives, Sayers et al. (2003) argue that it could in the process compromise clarity, consistency and accountability and proposed a compensatory method to combine the various criteria. Indeed, the large number of indicators may hinder the application of a fully non-compensatory multi-criteria approach, and calls for the integration of indicators in a systematic way. Data envelopment analysis techniques, which are commonly used for benchmarking in operations management, have been applied to public transport performance by Chu and Fielding (1992), Karlaftis (2004) and Yu and Fan (2009). Borger et al. (2002) provide a comprehensive review of the theory and applications of using frontier methods to analyze public transport efficiency with a focus on sector organization aspects.

In recent years, several works implemented MCDM for evaluation purposes in the field of public transport systems. Yeh et al. (2000) utilized MCDM for evaluating the performance of bus companies. Zak (2011) proposed two possible application of the MCDM methodology in public transport systems. In that work, multiple objective evaluation of development scenarios of the mass transit system (based on the passengers' and operator's point of view) and optimization of the crew size in a mass transit system were studied. Note that, to the best of our knowledge, none of the existing works in the literature used MCDM methods for assessing the performance of a multimodal public transport system from the perspective of different stakeholders with conflicting interests.

This study proposes a multi-criteria decision making (MCDM) modelling framework for the appraisal of multi-modal urban public transportation services. Alternative approaches are examined in order to assess their consistency and practical usefulness as a performance indicator. The framework embraces both compensatory and non-compensatory approaches including lexicographic, simple additive weighting (SAW), technique for order preference by similarity to the ideal solution (TOPSIS) and Concordance Analysis. The different methods and their formulations are presented in the following section. These methods are applied on survey data collected through a questionnaire in Teheran, Iran. The survey encompassed passengers, operators and the wider community and inquired about the perceived attributes of three urban public transport modes: regular bus (RB), bus rapid transit (BRT) and rail rapid transit (RRT). A brief introduction to the Teheran urban public transport system is presented in Section 3. Section 4 discusses the database structure and presents the definition of the 17 evaluation criteria utilized in the survey. According to the clustering techniques and factor analysis carried out in Keyvan-Ekbatani and Vaziri (2012), the 17 appraisal factors cover seven key dimensions: sustainable transport, reliability, trip attractiveness, comfort, convenience, attractiveness for the operator and service to the passengers. Results are reported in Section 5 where the aforementioned MCDM techniques were applied to rank the performance of the three studied transit modes. Finally, Section 6 discusses how the outputs of this study can be instrumental in supporting planning decisions and prioritizing measures to improve public transport services.

2. A review of applied MCDM methods

Multiple criteria decision making (MCDM) refers to making decisions in the presence of multiple, usually conflicting, criteria. MCDM models are known for evaluating a finite set of alternatives with respect to multiple criteria. Since there are too many techniques involved, Hwang and Yoon (1981) provided a taxonomy for classifying the techniques as: the types of information, salient features of information, and a major class of methods. Alternatives represent the different choices of action available to the decision maker. Usually, the set of alternatives is assumed to be finite, ranging from several to hundreds. They are supposed to be screened, prioritized and eventually ranked. In most MCDM applications the main purpose is to obtain the overall preference values of the alternatives on an acceptable scale. Keyvan-Ekbatani and Vaziri (2012) asserted that the appraisal of urban public transportation services inherently constitutes a MCDM situation due to the presence of conflicting evaluation factors.

In this section, first, the decision matrix in MCDM methods is explained. Then, the methodology to derive the weights of each appraisal criteria is presented. This is followed by a detailed explanation of the MCDM methods (i.e. Lexicographic, SAW, TOPSIS and Concordance Analysis) which are applied to determine the ranking of the alternatives in this work. Each MCDM involves three main steps (Triantaphyllou, 1997):

(a) determining the relevant criteria and alternatives
(b) calculating the relative importance, i.e. weights of criteria
(c) ranking the alternatives.

2.1. Decision matrix

A MCDA problem could be represented using a decision matric. A problem with m alternative options and n appraisal criteria, can be described by a matrix of $m \times n$ elements. Each element, such as X_{ij}, is either a single numerical value or a single grade, representing the performance of alternative A_i when it is evaluated in terms of decision criterion C_j.

$$D = \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & \cdots & C_n \end{array} \\ \begin{bmatrix} X_{11} & \dots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \dots & X_{mn} \end{bmatrix} \end{array} \qquad \left(i = 1,2,3,...,m \text{ and } j = 1,2,3,...,n\right) \tag{1}$$

2.2. Weighting method

Most of the MCDM methods require a relative importance or weight of each criterion with respect to their impact on the decision problem. Keyvan-Ekbatani and Vaziri (2012) converted the rank order of the appraisal criteria (i.e. specified by the respondents in the questionnaire-based survey) to numerical scores in order to analyze the data statistically. An ad-hoc procedure has been proposed assuming that each respondent has to distribute 100 points among the selected criteria according to their importance rank. A linear scale has been employed in order to distribute the scores among the chosen criteria. A respondent with only one chosen appraisal criterion is assumed to give all 100 points to that single criterion. A respondent with two important criteria is assumed to allocate the points in a ratio of 2:1, resulting in a score of 66.67 for the most important criterion and 33.33 for the other. In general, the scores of the criteria might be derived as following

$$S_{jl} = \frac{100\left(N_l + 1 - K_{jl}\right)}{\sum_{k=1}^{N_l} k} \tag{2}$$

$$S_j = \frac{\sum_{l=1}^{N} S_{jl}}{FS_j} \tag{3}$$

where N is the number of participants, N_l is the number of selected factors by the respondent l, K_{jl} is the rank of criterion j by participant l and S_{jl} is the score of factor j by respondent l. In case a factor was not chosen, the score will be assumed zero. In equation (3), S_j is the average score of the factor j and FS_j is the frequency of selecting the criterion j. To derive the weight of each criterion, the following equation is deployed

$$W_j = \frac{N_j \cdot S_j}{\sum_{j=1}^{n} N_j \cdot S_j} \tag{4}$$

$$\sum_{j=1}^{n} W_j = 1 \tag{5}$$

where W_j is the weight of C_j, and N_j is the frequency that C_j was selected.

2.3. Ranking the alternatives

The lexicographic method, SAW (Simple Additive Weighting), TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution) and concordance-discordance analysis are applied to evaluate the performance of the three public transport modes (i.e. alternatives) based on the appraisal criteria (i.e. 17 criteria in this study). In the following sections, we elaborate on each of the aforementioned methods.

2.3.1. Lexicographic method

Lexicographic ordering (LO) is a MCDM method that can potentially avoid the use of the weight factors by incorporating priorities of the individual planning criteria (objective functions) explicitly in the ranking process. In the lexicographic method, the alternative with the best performance on the most important criterion will be chosen. If there are ties between the alternatives, the performance of the tied alternatives will be compared on the next important criterion (Linkov et al. 2004). The LO method solves a sequence of small optimization problems in order of priority as follows

$$\mathrm{A}_h = \{\mathrm{A}_i \mid \max\,(\mathrm{X}_{ih})\} \qquad i = 1, 2, \ldots, m \tag{6}$$

where A_h is the alternative (i.e. mode in this work) with the highest X_{ih} value for C_h which is indicated as the most important criterion in the decision matrix.

2.3.2. SAW method

Simple Additive Weighting method is widely used because of its simplicity (Zanakis 1998). SAW is based on the average of weighted scores. This method was initially utilized by Churchman and Ackoff (1954) for coping with portfolio selection problems. To make all the ratings comparable, the normalization of decision matrix is required. An evaluation score for the alternatives can be calculated by summing up the multiplication of the weight of each criterion W_j and the related normalized preferred rating R_{ij} .The larger the R_{ij} value the better the performance of the public transport mode. The best alternative can be obtained by the following equation

$$A^* = \left\{ A_i \mid \max \sum_{j=1}^{n} W_j \cdot R_{ij} \right\} \tag{7}$$

R_{ij} the normalized preferred rating is determined by equation (8)

$$R_{ij} = \frac{X_{ij}}{X_{ij}^*} \tag{8}$$

where X_{ij}^* is the maximum value in each column of the decision matrix.

2.3.3. TOPSIS

TOPSIS is based on the concept that the ideal alternative has the best level for all criteria, whereas the least desired alternative is the one with all the worst criteria values (Wang et al. 2008). Hwang and Yoon (1981) proposed TOPSIS as a technique for order preference by similarity to ideal solution in order to find the best alternative of a MCDM problem. The method is based on the principle of compromise solution that says the best alternative should have the shortest Euclidean distance from the positive ideal solution (PIS) and the farthest Euclidean distance from the negative ideal solution (NIS). TOPSIS method has been used for evaluation and selection of alternatives for MCDM problems with a finite number of alternatives by Hwang et al. (1993). The following procedure is carried out to evaluate the performance of the alternatives:

(a) Normalizing the elements of the decision matrix using Eq. (9)

$$R_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} . \tag{9}$$

(b) Determining the weighted normalized vector $V_{ij} = W_j \cdot R_{ij}$.

(c) Deriving the PIS (A^+) and NIS (A^-) soloutions from the following set of equations

$$A^+ = \left\{ \left(\max V_{ij} \mid j \in J \right), \left(\min V_{ij} \mid j \in J' \right) \right\} = \left\{ V_1^+, V_2^+, \ldots, V_n^+ \right\} \qquad J + J' = n \tag{10}$$

$$A^- = \left\{ \left(\min V_{ij} \mid j \in J \right), \left(\max V_{ij} \mid j \in J' \right) \right\} = \left\{ V_1^-, V_2^-, \ldots, V_n^- \right\} \tag{11}$$

where J and J' are associated with the benefit and the cost attributes respectively.

(d) Compute the distances S_i^+ and S_i^- of each alternative from A^+ and A^- according to (12) and (13).

$$S_i^+ = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^+\right)^2} \tag{12}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^-\right)^2} \tag{13}$$

(e) Obtaining the relative closeness index C_i^+ to the ideal A^+.

$$C_i^+ = \frac{S_i^-}{\left(S_i^+ + S_i^-\right)} \tag{14}$$

(f) Ordering the alternatives (the larger the closeness index value, the better the performance)

2.3.4. Concordance analysis

The concordance-discordance concept was first introduced by Roy (1968). This principle suggests the best alternative by a series of pair-wise comparison across the set of objectives (Giuliano 1985). To compare two non-zero alternatives *i* and *i'* and measure the relative advantage of one alternative over the other, two indices called the concordance index $CI_{ii'}$ and the discordance index $DI_{ii'}$ are applied. The Concordance analysis method consists of the following steps

(a) Calculating the normalized decision matrix R_{ij} by utilizing (8).
(b) Determining the concordance set $CI_{ii'}$ and the discordance set $DI_{ii'}$

$$C_{ii'} = \left\{ j \mid R_{ij} > R_{i'j} \right\} \tag{15}$$

$$D_{ii'} = \left\{ j \mid R_{ij} \le R_{i'j} \right\}. \tag{16}$$

(c) The Concordance and discordance Indexes can be obtained as below

$$CI_{ii'} = \sum_{j \in C_{ii'}} W_j \tag{17}$$

$$DI_{ii'} = \frac{1}{m}\sum_{j \in D_{ii'}} \frac{W_j\left(\left|R_{i'j} - R_{ij}\right|\right)}{d_{\max}} \qquad d_{\max} = \max_{(i,i'),\, j \in D_{ii'}} W\left(\left|R_{i'j} - R_{ij}\right|\right) \qquad m = \max_{(i,i')}\left\{\left|D_{ii'}\right|\right\} \tag{18}$$

where m indicates the number of members in the discordance set.

(d) Deriving the net concordance index (NCI) and net discordance index (NDI) according to (19) and (20)

$$NCI_i = \sum_{i'} CI_{ii'} - \sum_{i'} CI_{i'i} \tag{19}$$

$$NDI_i = \sum_{i'} DI_{ii'} - \sum_{i'} DI_{i'i}. \tag{20}$$

The set of alternatives with positive NCI_i and negative NDI_i for a weighted system comprises the set of dominant alternatives.

3. Case study: Teheran Public Transport

Over the past years, the worsening traffic congestion has become more than a nuisance and turned into a major challenge for the Tehran City authorities. The metropolitan region is growing at a rate of about 1% annually so any new transportation service in Tehran needs to cater for not only the growing demand but also be adapted to the development and expansion of the city. In addition, the transportation system also has to satisfy the general public's rising expectations in terms of quality of life and environmental concerns. Purchasing motorized vehicles is still considered relatively expensive. Up until 2009 fuel was heavily subsidized, whereas new measures were then introduced to realign the price of fuel and reduce its usage. It is estimated that more than 3.5 million vehicles travel on Tehran's road network and today the municipality estimates that some 19 million daily trips are made in Tehran (Hashemi, 2010a) 22% of trips are made by bus, 23% by shared taxi, 12% by metro, 10% by minibus, 7% walking and cycling and the rest by private car (28%). The latter were responsible for 88% of local air pollution annually (Hashemi, 2010b). The metro (underground) has enjoyed some considerable success and has been in operation for the past 12-13 years. It now carries nearly 2 million passengers/trips a day, representing 12% of the total number of trips made in Tehran. By 2010 lines 1, 2, 4 and 5 are operational and 125 metro track-kilometres have been built. The first BRT line was introduced in Tehran in 2007, inspired by the famous TransMilenio BRT in Bogotá, Columbia. Ridership increased from 214,000 to 380,000 passengers per day in the period between May 2007 and May 2008.

4. Data base

The data collected for this study were obtained as a part of a survey that targeted three groups of respondents: (a) passengers; (b) operators (experts, station operators), and; (c) non-users. Data collected in the form of a questionnaire survey. From the list of evaluation criteria, the respondents were asked to select any number of criteria that they felt were important in public transport appraisal. Then from the list of factors selected, each respondent was asked to rank the factors in order of importance.

The questionnaires were sent to Tehran and Suburb Bus Company and also Tehran Metro Company. For the groups of passengers and community, the students of the Department of Civil Engineering of Sharif University of Technology, Teheran, Iran, were chosen. Three classes of B.Sc. students and one class of M.Sc. students expressed their opinion about the aforementioned factors. To separate the group of passengers and community from each other, it was decided to regard the students with medium and high public transport usage frequency as passengers and the rest as non-users. Fig. 1 demonstrates the composition of the groups of participants in this study. Due to several incomplete questionnaires, 154 out of 180 were utilized in the database. The structure of the questionnaire and the information obtained is displayed in Fig. 2. Three type of data have been derived from the questionnaire:

1) Socioeconomic (e.g. age, sex, occupation, number of owned cars).
2) Assessment of each public transport mode (on a 5 points scale - very poor (1), poor, fair, good, very good (5)) based on the 17 appraisal criteria provided in the questionnaire (see Fig. 2).
3) The set of important criteria for public transport evaluation along with the corresponding rankings according to the respondents' opinion.

The decision matrix of each alternative was derived and the MCDM methods described in section 2 were applied.

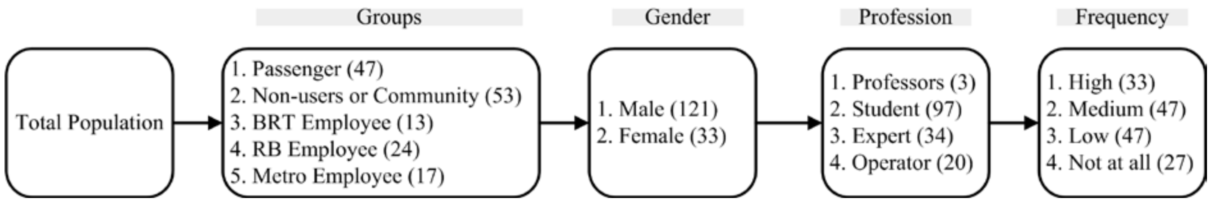

Fig. 1 Respondent's structure (from Keyvan-Ekbatani and Vaziri, 2012)

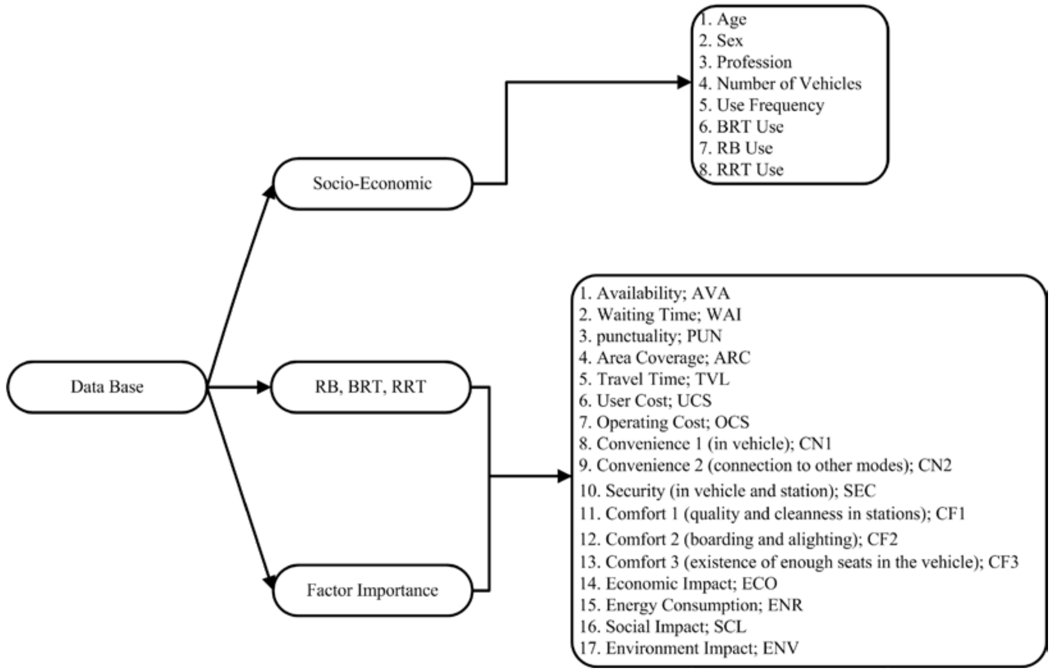

Fig. 2 Data base structure

5. Results: Teheran public transport multi-criteria evaluation

In this section, the MCDM methods explained in Section 2 are implemented on the database described in Section 4 to evaluate the three different public transport modes in Teheran (i.e. metro, regular bus and bus rapid transit) from the perspectives of passengers, non-users and operators, as well as considering them jointly. First, the decision matrices of each group are derived. In section 5.2 the weights of the 17 criteria are presented. This is followed by multi-criteria evaluation of the alternatives according to decision matrices of the aforementioned groups.

5.1. Decision matrix

The decision matrix of each group of participants in the survey is depicted in Table 1. The numerical values in Table 1, indicate the average qualitative score (i.e. 1 to 5) given to each of the criterion by the respondents. For instance, the passengers gave a high score (4.66) to the environmental impact of RRT.

5.2. Criteria weights

By applying the methodology addressed in section 2.2, the weight of each criterion from perspective of the different groups is derived and presented in Table 2.

5.3. Lexicographic ordering

This method is independent of the weights of the criteria. The most important criteria is chosen based on the rankings which the respondents have given to the criteria in the questionnaire. According to groups of total, passenger, community, and operator the most important factors are WAI, WAI, TVL and WAI respectively. Table 3 summarizes the result of a lexicographic evaluation of the three public transport modes based on the data of the each group. The results revealed that RRT is the best alternative according to all groups (the maximum value of decision matrix for the aforementioned four criteria is indicated by (*) in Table 3.

Table 1 decision matrices of different groups: (a) total population; (b) passenger; (c) community; (d) operator

(a)	AVA	WAI	PUN	ARC	TVL	UCS	OCS	CN1	CN2	SEC	CF1	CF2	CF3	ECO	ENR	SCL	ENV
RB	3.22	2.36	2.37	3.44	2.35	4.16	2.91	2.00	3.44	2.92	2.50	2.75	2.04	3.88	3.67	3.81	2.84
BRT	4.01	3.75	3.79	3.17	3.94	4.45	2.97	2.54	3.37	3.29	3.52	3.09	2.17	4.12	4.17	4.16	3.75
RRT	4.05	3.92	3.99	3.23	4.12	4.14	3.41	2.99	3.51	3.64	4.23	3.09	2.26	4.12	4.52	4.05	4.68
(b)	AVA	WAI	PUN	ARC	TVL	UCS	OCS	CN1	CN2	SEC	CF1	CF2	CF3	ECO	ENR	SCL	ENV
RB	3.17	2.34	2.45	3.51	2.45	4.21	3.04	2.04	3.53	2.91	2.40	2.81	2.15	4.04	3.77	3.79	3.06
BRT	3.91	3.89	3.87	3.38	4.02	4.51	3.11	2.26	3.32	3.26	3.68	2.91	1.94	4.30	4.34	4.26	3.85
RRT	3.98	3.96	4.17	3.28	4.21	4.34	3.55	2.70	3.47	3.60	4.45	2.87	1.87	4.21	4.57	4.19	4.66
(c)	AVA	WAI	PUN	ARC	TVL	UCS	OCS	CN1	CN2	SEC	CF1	CF2	CF3	ECO	ENR	SCL	ENV
RB	3.13	2.09	1.96	3.09	1.92	4.08	3.06	1.53	3.21	2.75	2.23	2.60	1.70	3.68	3.38	3.70	2.40
BRT	3.75	3.53	3.51	3.02	3.64	4.34	3.21	2.15	3.30	3.17	3.42	2.96	1.87	3.96	4.04	3.94	3.51
RRT	3.98	3.77	3.85	2.98	3.94	4.06	3.49	2.62	3.49	3.40	4.28	3.11	2.04	4.00	4.53	3.79	4.66
(d)	AVA	WAI	PUN	ARC	TVL	UCS	OCS	CN1	CN2	SEC	CF1	CF2	CF3	ECO	ENR	SCL	ENV
RB	3.35	2.63	2.70	3.70	2.69	4.20	2.65	2.43	3.59	3.09	2.85	2.83	2.28	3.93	3.87	3.94	3.09
BRT	4.33	3.83	3.98	3.13	4.17	4.50	2.61	3.17	3.48	3.44	3.48	3.37	2.67	4.13	4.15	4.30	3.89
RRT	4.17	4.04	3.96	3.44	4.22	4.06	3.20	3.61	3.56	4.00	3.26	2.81	4.15	4.21	4.46	4.19	4.70

Table 2 Weights of the criteria in each of the four groups

Groups	AVA	WAI	PUN	ARC	TVL	UCS	OCS	CN1	CN2	SEC	CF1	CF2	CF3	ECO	ENR	SCL	ENV
Total	0.06	0.13	0.10	0.06	0.12	0.05	0.02	0.07	0.04	0.04	0.02	0.02	0.07	0.04	0.05	0.03	0.10
Passenger	0.05	0.19	0.18	0.05	0.17	0.04	0.00	0.08	0.02	0.02	0.01	0.02	0.07	0.01	0.02	0.01	0.07
Community	0.04	0.16	0.09	0.06	0.17	0.02	0.00	0.14	0.02	0.04	0.01	0.01	0.05	0.01	0.06	0.01	0.12
Operator	0.06	0.19	0.10	0.04	0.11	0.05	0.02	0.04	0.02	0.01	0.01	0.01	0.03	0.04	0.06	0.05	0.18

Table 3 Lexicographic method results

	Groups			
	Total	Passenger	Community	Operator
Important Criteria	WAI	WAI	TVL	WAI
RB	2.35	2.34	1.92	2.63
BRT	3.94	3.89	3.64	3.83
RRT	4.12*	3.96*	3.94*	4.04*

Table 4 SAW method results

	Groups			
	Total	Passenger	Community	Operator
RB	0.73	0.71	0.63	0.74
BRT	0.92	0.93	0.89	0.93
RRT	0.99*	0.98*	1.00*	0.99*

5.4. SAW

The decision matrices are normalized by applying (8). The results of implementing this popular MCDM method on the database is presented in Table 4. As it is shown in Table 4 (by *), the best performance of public transport in Teheran is yield by RRT (metro) according all the participated groups in the survey.

5.5. TOPSIS performance analysis

The performance of the three public transport modes are analyzed by implementing TOPSIS method. As pointed out in section 2.3.3, the alternative (or mode) with the higher closeness index value C_i*, is the better performer. Thus, for deriving C_i* value, S^+ and S_i^- are calculated and reported in Table 5. According to the final rankings

Table 5 TOPSIS method results (S^+, S_i^- and C_i*) along with the rank of the modes for different groups of stakeholders

Group	Alternative	S_i^+	S_i^-	C_i*	Rank
Total	RB	0.071	0.010	0.124	3
	BRT	0.024	0.059	0.707	2
	RRT	0.017	0.069	0.800	1
Passenger	RB	0.036	0.000	0.000	3
	BRT	0.010	0.032	0.760	2
	RRT	0.000	0.036	1.000	1
Community	RB	0.053	0.000	0.000	3
	BRT	0.024	0.037	0.604	2
	RRT	0.000	0.053	1.000	1
Operator	RB	0.084	0.081	0.491	3
	BRT	0.020	0.103	0.838	2
	RRT	0.081	0.084	0.509	1

Table 6 Concordance/discordance results

Group	RB		BRT		RRT		Good Alternatives
	NCI	NDI	NCI	NDI	NCI	NDI	
Total	-	+	+	-	+	-	BRT, RRT
Passenger	-	+	+	-	+	-	BRT, RRT
Community	-	+	+	-	+	-	BRT, RRT
Operator	-	+	+	-	+	-	BRT, RRT

obtained by the TOPSIS closeness index, C_i*, RRT is the best public transport mode based on each of the four studied groups. The performance of BRT and RB are ranked as second and third respectively (See Table 5 for more details).

5.6. Applying concordance/discordance analysis on database

To analyze the performance of the three different modes based on concordance/discordance method, the sign of NCI_i and NDI_i is specified for different respondent groups and presented in Table 6. According to Table 6, both RRT and BRT have an acceptable performance from the perspective of all the groups involved in the study, since these two modes have positive *NCI* and negative *NDI*.

6. Conclusion

A recent study suggested that an efficient evaluation of public transport systems should consider different groups of people with various perspectives and potentially conflicting interests (Keyvan-Ekbatani and Vaziri, 2012). Moreover, the large number of aspects involved in public transport appraisal call for the deployment of MCDM methods in evaluating alternative transit modes. In this paper, various MCDM schemes are proposed and implemented on a database derived from a questionnaire survey which considers the perception of three groups of stakeholders (i.e. operators, passengers and non-users) for a multi-criteria evaluation of Teheran urban public transport system. The results unveiled that the RRT or metro system in Teheran has the best performance as compared with BRT and regular bus modes based on the results obtained from the MCDM analysis. These results might assist decision makers in enhancing the quality of the system according to the importance of each criterion and the ranking of the alternatives.

The MCDM also enables to reveal which service aspects are considered as the most important determinants of overall performance. When considering all the respondents jointly, waiting time, travel time, punctuality and environmental impact were the most important factors which accounted together for 45% of the weights. From passengers' perspective, importance was much more concentrated with waiting time, travel time and punctuality accounting for 54% of all weights. Non-users are more concerned than passengers about in-vehicle convenience. Operators assign equal importance to waiting time as passengers do, but assign less importance to travel time and in-vehicle convenience. In contrast, operators give more importance to economic impact, energy consumption, social impact and environmental impact (a total of 33%) than passengers (10%) and non-users (19%). All of the respondent groups gave little importance to operating cost and comfort in terms of station conditions and embarking and disembarking, whereas seat availability has a moderate level of importance. Operating cost was presumably not considered by operators as an important determinant of performance because it is conceived as the price tag (input) of obtaining a certain level of service (output) rather than a performance aspect in its own right. Future research may consider fuzzy MCDM appraisal for a more precise evaluation of a multi-modal urban public transport system.

References

Borger, B.D., Kerstens, K., Costa, A., 2002. Public transport performance: What does one learn from frontier studies?. Transport Reviews, 22 (1), 1-38.

Cats, O., Abenoza, R.F., Liu, C., Susilo, Y., 2015. Identifying priority areas based on a thirteen years evolution of satisfaction with public transport and its determinants. Proceedings of the 94th Transportation Research Board Annual Meeting, Washington DC.

Churchman, C.W., Ackoff , R.L., 1954. An approximate measure of value. Journal of the Operational Research Society of America 2, 172–187

Chu, X., Fielding, G.J., 1992. Measuring transit performance using data envelopment analysis. Transportation Research Part A 26 (3), 223-230.

Giuliano, G., 1985. A multicriteria method for transportation investment planning. Transportation Research Part A 19, 29-41.

Hashemi, M., 2010a. Tehran transportation and traffic system' a background paper prepared for Institute Transportation Development Policy (ITDP) Sustainable Transport Awards 2010.

Hashemi, M., 2010b. Increasing efficiency of Tehran public transport system by increasing the metro capacity. Presentation made at the 1st UITP Eurasia Congress, 6– 8 September, Moscow, Russia.

Hwang, C., Yoon, K., 1981. Multiple attribute decision making methods and applications. Springer.

Hwang, C., Lai, Y., Liu, T., 1993. A new approach for multiple objective decision making, Computers and Operations Research 20, 889-899.

Karlaftis, M.G., 2004. A DEA approach for evaluating the efficiency and effectiveness of urban transit systems. European Journal of Operational Research, 152 (2), 354-364.

Keyvan-Ekbatani, M., Vaziri, M., 2012. Perceived attributes in multidimensional appraisal of urban public transportation. Procedia-Social and Behavioural Sciences 48, 2159-2168.

Linkov, I., Varghese, A., Jamil, S., Seager, T. P., Kiker, G., Bridges, T., 2004. Multi-criteria decision analysis: a framework for structuring remedial decisions at contaminated sites. Comparative risk assessment and environmental decision making 38, 15-54.

Macharis, C., de Witte, A., Ampe, J., 2009. The multi-actor, multi-criteria analysis methodology (MAMCA) for the evaluation of transport projects: Theory and practice. Journal of Advanced Transportation 43 (2), 183-202.

Roy B., 1968, Classement et choix en présence de points de vue multiples (la méthode ELECTRE), RIRO 8, 57-75.

Sayers, T.M., Jessop, A.T., Hills, P.J., 2003. Multi-criteria evaluation of transport options – flexible, transparent and user-friendly? Transport Policy 10 (2), 95-105.

Stradling, S., Anable, J., Carreno, M., 2007. Performance, importance and user disgruntlement: a six-step method for measuring satisfaction with travel modes. Transportation Research Part A 41, 98–106.

Susilo, Y., Cats, O., 2014. Exploring key determinants of travel satisfaction for multi-modal trips by different traveler groups. Transportation Research Part A: Policy and Practice 67, 366-380.

TCRP, 1995. Synthesis 10: Bus route evaluation standards. Transportation Research Board of the National Academies, Washington, D.C.

TCRP, 1999. Report 47: A Handbook for measuring customer satisfaction and service quality. Transportation Research Board of the National Academies, Washington, D.C.

TCRP, 2003. Report 100: Transit capacity and quality of service manual, 2nd ed. Transportation Research Board of the National Academies, Washington, D.C.

Triantaphyllou, E., 1997. A sensitivity analysis approach for some deterministic multi-criteria decision making methods. Decision Sciences 28, 151-194.

Vuchic V., 2004. Urban transit: operations, planning and economics. Willey.

Wang, J. J., Jing, Y.Y., Zhang, C. F., Shi, G. H., Zhang, X. T., 2008. A fuzzy multi-criteria decision-making model for trigeneration system. Energy Policy 36 (10), 3823-3832.

Yeh, C. H., Deng, H., Chang, Y. H., 2000. Fuzzy multicriteria analysis for performance evaluation of bus companies. European Journal of Operational Research, 126 (3), 459-473.

Yu M-M. and Fan C-K., 2009. Measuring the performance of multimode bus transit: A mixed structure network DEA model. Transportation Research Part E, 45 (3), 501-515.

Zak, J., 2011. The methodology of multiple criteria decision making/aiding in public transportation. Journal of Advanced Transportation, 45, 1-20.

Zanakis, S. H., Solomon, A., Wishart, N., Dublish, S., 1998. Multi-attribute decision making: A simulation comparison of select methods. European journal of operational research 107(3), 507-529.