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A fuzzy-based multi-dimensional and multi-period service quality evaluation outline for rail transit systems☆

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ABSTRACT

As a public transportation mode, rail transit systems are one of the most preferred modes to avoid traffic congestion, especially during the rush hours. This paper proposes a service quality evaluation outline to measure rail transit lines' performances via passenger satisfaction surveys. The proposed method combines statistical analysis, fuzzy trapezoidal numbers and TOPSIS to evaluate service quality levels for multi periods. In total 17,769 surveys that are conducted in Istanbul in 2012, 2013, and 2014 are considered to determine the factors need to be improved. We provide recommendations to enhance the operation for specific lines and guidelines for future investments.

1. Introduction

Service quality (SQ) level in public transportation (PT) is a crucial indicator for authorities and decision makers for determining the performance of a service. Therefore, SQ level should be evaluated periodically by service providers to designate the effectiveness of the services. This evaluation process should contain not only main activities, and forecasted demand but also unsatisfied service needs and interests of shareholders (Hassan et al., 2013). Service provider`s SQ level and economic performance can be obtained by the evaluation of the system performance (Transportation Research Board, 2003). Evaluation processes should contain evaluation of many factors related to SQ factors in customer satisfaction assessments (Awasthi et al., 2011).

User perceptions and expectations are two important issues that should be considered during the evaluation process (Filipović et al., 2009). Correspondingly, Berry et al. (1990) pointed out that the users are the only judges of the SQ, as mentioned in de Oña et al. (2012). SQ has chance to be improved once the users perceptions and expectations are captured and the performance of the system is determined. In parallel, Tyrinopoulos and Antoniou (2008), Eboli and Mazzulla, (2009, 2011) and de Oña et al. (2013) considered users perceptions in determining SQ as well. Besides perceptions, both objective and subjective factors should be considered in SQ evaluation (Eboli and Mazzulla, 2008). Redman et al. (2013) determined the factors, which relates to PT, needed to be enhanced to attract the private car users. They obtained that service reliability and frequency are the factors that affect private car users the most. On the other hand, Mouwen and Rietveld (2013) found that brand new cars have higher influence on users as well. Conformably, dell'Olio et al. (2011) determined cleanliness, waiting time, and comfort as the highest influencing factors on users' perceptions. Additionally, waiting time, journey time and the occupancy are determined as the most significant factors for the potential users.

Rail transit (RT), as a type of PT catches many researchers' attention and several studies are performed in this area (Baum-Snow et al., 2005; Pan et al., 2010; Scherer, 2010; Özgür, 2011; Givoni and Banister, 2012). Vuk (2005) carries out an analysis to determine the effect of the metro line of the city of Copenhagen on traffic. He noted that metro positively affects the traffic between 13% and 18%. Diana (2012) investigated the satisfaction of users who travel with different urban areas` RT lines. He observed that smaller towns` RT line users have higher satisfaction in terms of SQ than metropolitan cities` RT line users. Similarly, Litman (2007) concluded that, enhancing RT`s SQ reduces the delay or number of automobile/bus trips, which effects all users. Lastly he mentioned that high SQ in RT encourages users to drive less and walk, if they live in a more automobile dependent area. Garrett (2004) concluded that the traffic congestion is reduced in several cities of US after light RT lines are developed and, consequently, average travel time is reduced in the areas that are located near RT lines (Baum-Snow et al., 2005). Likewise, Nelson et al. (2006) noted that Washington DC's RT services provide benefits in terms of traffic congestion-reduction.

Nathanail (2008) evaluated the performance of Hellenic Railways based on 22 criteria, which are gathered under six main factors: itinerary accuracy, system safety, cleanness, passenger comfort, servi-

☆ Dedicated to the memory of Adil Kolukısaoğlu who died in a work accident in Mecidiyeköy-Beşiktaş-Kabataş RT line construction project, in 2015.

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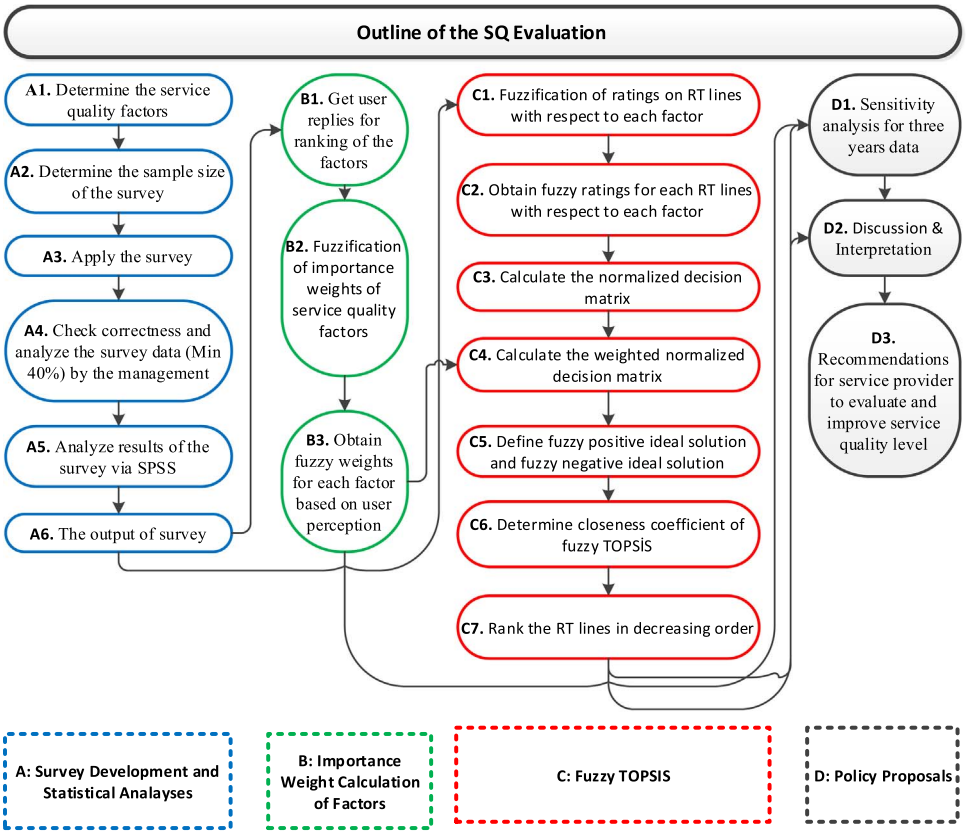

Fig. 1. Outline of the SQ evaluation for RT services.

cing, and passenger information. They concluded that the RT system performs the best on the itinerary accuracy and system safety. Brons et al. (2009) determined how significant the 'access-to-the-station' to users in their total satisfaction, and the balance between features of the RT services. They found that, in several parts of the RT network, improving and increasing access services to the railway stations could substitute for improving and increasing the services provided, and this may attract users who use other types of transportation modes. Nevertheless, user perception on SQ may change depending on the category of users being considered (dell'Olio et al., 2010). de Oña et al. (2014b) assessed SQ considering different groups of users with different perceptions. They conclude that the most important factors are different for each group of users. de Oña et al. (2015a, 2015b) calculated the index numbers on the basis of data collected from surveys during the years of 2007 and 2013, in which they considered both perceptions of users and importance rates to determine the SQ levels. Therefore, evaluating SQ level needs to consider multiple factors to get accurate results. Thus, multi criteria decision making (MCDM) methods are efficient approaches for this purpose.

MCDM is a strong tool for SQ evaluation as used in Nathanail (2008), Zak (2011), Awasthi et al. (2011), Hassan et al. (2013), Celik et al. (2013), Celik et al. (2014), Aydin et al. (2015). Another advantage of MCDM procedures is that they are flexible to be combined with one another and with mathematical modeling techniques. For instance, Awasthi et al. (2011) combined SERVQUAL and TOPSIS to evaluate the SQ for Montreal metro lines. Aydin et al. (2015) evaluated SQ level of RT of Istanbul considering one year survey data (2013). They proposed a combined framework of statistical analysis, fuzzy analytic hierarchy process, trapezoidal fuzzy sets and Choquet integral to evaluate SQ levels.

We provide a general SQ evaluation outline to measure multi-periods RT lines' performances in Istanbul, by proposing a combined method of statistical analysis, trapezoidal fuzzy numbers and TOPSIS. The contributions of this study are as: (1) The factors determined here are based on a SQ survey conducted with 17.769 passengers of RT lines in Istanbul, which has a strong merit for gathering true perceptions of users; (2) method provides a solid SQ evaluation process by integrating survey study, statistical analysis and MCDM; (3) since trapezoidal fuzzy numbers have the capability of handling more uncertainty, ambiguity and vagueness they are used to represent the perception of users; (4) the proposed method provides valuable guidelines for future investments in RT systems and can be applied to any metropolitan cities' and at any size of RT services. (5) the proposed method is applicable to evaluate SQ level for multi periods as applied here for three periods (2012, 2013, and 2014); (6) besides RT, proposed method can be applied to all type of complex decision making problems to handle vague, unknown and subjective or uncertain data.

The rest of the paper is structured as follows. §2 describes the proposed method. §3 introduces the gathered data and presents statistical analyses. §4 presents the application of the SQ evaluation for multi periods and provides results and discussions. Recommendations and conclusions are provided in §5.

2. Methodology

First, we introduce an outline for multi-period multi-dimensional MCDM process to evaluate the SQ level in RT. Later, we explain the basic definition of trapezoidal fuzzy numbers (Buckley, 1985; Liu et al., 2012; Liu et al., 2014), TOPSIS (Hwang and Yoon, 1981; Chen and Hwang, 1992; Yoon and Hwang, 1995; Behzadian et al., 2012), and Fuzzy-TOPSIS (Chen, 2000; Yong, 2006; Kaya and Kahraman, 2011; Behzadian et al., 2012).

2.1. Outline of the service quality evaluation

The proposed outline is constructed based on the concept of