



Evaluation of Quality in Public Transport Services: The Use of Quality Dimensions as an Input for Fuzzy TOPSIS

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Abstract The assessment of the quality of service provided by organizations plays a key role in the continuous improvement of the quality management system. When it comes to the quality of public transportation, the theme becomes even more relevant since user satisfaction influences the perception of a better quality of life. One of the modes of public transport that stands out in Brazil is the Bus Rapid Transit (BRT) system, characterized by fast passenger transportation since it uses exclusive runways and promotes faster locomotion and less pollution of gases. In the Northeast region of Brazil, the current system has operated since 2014 with two large corridors with a length of 25 km and carrying more than 830 thousand people daily. Due to the importance of the fast passenger transport sector, it is necessary to evaluate the quality of the service provided. In this sense, the present work proposes an approach to evaluate the public transport services offered to users of the BRT system in the northeast of Brazil, through a structured questionnaire to measure customer

perception and applying the Fuzzy Set and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS). The motivation for choosing the Fuzzy Set is based on the data processing mode since fuzzy numbers simplify the expression of human judgment rather than its individual rationality, the translation of individual subjectivity, and data processing. The choice of TOPSIS for the possibility of ordering variables by means of comparison with the perfect alternative. The methodology of this article is considered a case study and 569 questionnaires were applied to BRT users. The result of the application of the approach showed that the best-evaluated variables are technical security and a single charge of the collection. On the other hand, there was a shortage of information about the schedules of the lines and the presence of convenience stores, demonstrating that these aspects can be developed for greater user satisfaction. It is believed that the proposed approach can contribute to the organizational context by guiding managers and establishing a logical set of procedures for assessing service delivery situations, revealing the level of adjustment required to achieve optimal service performance, and variables and quality dimensions by the best performance score according to the customer's perception.

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1 Introduction

The public transport moves the population of a city, interconnect them to other adjacent ones. Today, connection prompt urban mobility. The flow of the urban ways

and avoiding congestions coming from the great number of touring car circulating in the ways are indispensable in the cities, it helps in the locomotion of the population. In recent years, millions of people have lost money and time because of congestion [1] and there is a considerable increase in the price of car travel during congestion [2, 3].

In Brazil, demands for public transport have been falling in recent years, exceptionally in the most populous capitals, due to the expansion of mobility strongly supported in individual transport, especially in automobiles and motorcycles, the latter directly aggravating health costs in large metropolises. It is estimated that the decrease in the use of public transport in the last two decades is in the large Brazilian cities, between 20 and 30%, generating environmental impacts and increasing energy consumption [4, 5]. People chose a car, because it is convenience, has a freedom of movement. But public transportation offered time and a average quality on their services.

To solve the problem of public transport, several countries in the world (Colombia, Mexico, the United States, Japan and France) use the Bus Rapid Transit (BRT) concept as a backbone in the implementation of public urban development policies. The BRT system has an economical approach to public transport to many people, better flow, speed, timeliness, comfort and alignment of technology, service design and user interface [6]. This system is already being used in the cities of Curitiba, São Paulo, Bangkok [7], Beijing [5], Sydney [8] and is shown as a viable greater urban mobility.

The BRT is characterized by being a fast passenger transport that presents the quality of the rail transport and the flexibility of the bus system [9, 10]. The BRT vehicles use exclusive lanes, they have a higher average speed, resulting in better service and lower emissions of polluting gases. The technical characteristics adopted for the full operation of the BRT system, according to the National Association of Public Transport (ANTP) of Brazil, follow the following definitions: Exclusive band; Use central lanes, or sidewalk, or counter flow; has a range approximately 3.5 m wide; embarkation/disembarkation stations between 2.5 and 5.0 m; Overtaking range in stations at least 20 m wide; Average speed of 23–30 km/h; User clear signage, system maps, electronic dashboards at the stations announcing important information regarding timetables, lines and stopping points.

Although the exact costs of the BRT system depend heavily on local circumstances, typically capital costs and operating costs are lower than rail systems [5, 10]. In Brazil, the BRT system has been used by several cities, with 124 corridors destined to this system that cover 871 km, displacing more than 12 million people [11]. In the Metropolitan Region of Recife (MRR), located in northeastern Brazil, the current system has been operating

since 2014, being a strategy used by the state government in partnership with the federal government to ensure a better mobility of people, during the 2014 World Cup. The BRT in the MRR has two large corridors with a length of 25 km and displacing more than 830 thousand people daily [11].

Due to the importance of the fast passenger transport sector, it is necessary to evaluate the quality of the service provided and, therefore, correct the faults according to specifications, thus obtaining better results for the organization of the system and the quality of services provided.

Like all managerial actions, and especially those involving people, the evaluation tool is of great importance for corrective measures to be used to better serve the needs of users. The improvement of public transport services influences user satisfaction and quality of life assessment [12]. As a consequence of this influence, policymakers must establish policies that seek to maximize this state of social welfare, within economic and technological constraints. In order to support decision making, performance measures have become an essential tool for agencies to establish strategic goals for the continuous improvement of services provided [13].

Thus, many authors have been studying quality management in the public transport sector. In the studies of [14], a scale of measurement of quality of service was developed for the public transport that allowed the identification of three different dimensions of quality: Service Planning and Reliability; Comfort and Auxiliary Factors; and network design. Of these three dimensions, their analysis indicated that only the Comfort and the Auxiliary Factors affected the perceived satisfaction of the passengers and, consequently, the perceived quality of the services.

Chou et al. [15], carried out an analysis like the previous one for high-speed urban rail transport and developed an indicator of quality of service composed of five dimensions, but only three show a marked performance when considering their internal consistencies and are highly effective in explaining. The perception of satisfaction with the service, are: the tangible aspects of the environment, the convenience and the reliability of the service.

Addressing the topic of perceiving quality of service under a different direction, [16], use a 68 items measurement scale to evaluate the service aspects that bus users dislike about the service. Their analysis indicated that the following quality dimensions are apparent: Security, Service Delivery, Traffic Speed, Tariff Costs, Access Difficulties, and Service Marketing considerations.

Şimşekoğlu et al. [17] developed a perceived quality measurement scale for transportation services that identified three distinct dimensions that involve flexibility, convenience, and safety of the transportation system.

Considering the ways in which these dimensions can be used to explain the variance in the intention to make use of public transport, the results indicated that both convenience and perceived safety have a significant effect.

The findings of [17] are in convergence with those of [18], whose results suggest that public transport users consider the quality of service is related to functional service issues (such as information and interaction with employees), aspects of the physical environment (such as agglomeration, legroom and temperature) and convenience.

Morton et al. [19] using factor analysis and linear regression models to assess the quality of public transport in Scotland, identified three latent variables that impact user satisfaction: convenience, environment, and ease of use issues. In addition, the authors identified that the perceived convenience of the bus service had a significant positive impact on perceived satisfaction with the service, suggesting that improvements in frequency, availability, reliability, and service stability are likely to increase perceived satisfaction among existing passengers.

This range of evaluation approaches is justified since quality in services has a complex concept due to its three main properties: intangibility, heterogeneity, and inseparability [20]. Depending on these characteristics, users often have different perceptions about each service attribute because of their different service needs and preferences. According to [21] to achieve the desired quality of the customers, the companies work with a view to delivering a differentiated service, always seeking the improvement of the quality of their services. This improvement is due to the basic characteristics of the sector since the client evaluates the quality of the service that receives, being this evaluation determining to his satisfaction.

In this way, an important point raised by public transport companies is how to evaluate user satisfaction, since the models in the literature do not take into account the particularities of the service sector, as well as the subjectivity, ambiguity, and imprecision obtained through of customer responses. Moreover, the traditional methodologies used to evaluate BRT services in Brazil did not provide a comprehensive empirical performance analysis of BRTs that combines several input variables and their uncertainty.

Thus, despite the various approaches used to analyze the quality of public passenger transport services, it is necessary that hybrid models be used to quantitatively measure the quality of service, identifying critical factors that threaten or enhance the BRT system in Brazil.

According to this line of argument, this paper proposes an approach to evaluate the public transport services offered to users of the BRT system in the northeast of Brazil, through a structured questionnaire to measure

customer perception, applying the Fuzzy Set and the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS). In this approach, it was considered 24 variables that together formed seven dimensions of quality. From the evaluation of variables and dimensions of quality, the ordering of the tests using the TOPSIS multicriteria method was carried out, based on the theory of fuzzy systems and then the hypothesis tests were applied between the dimensions in order to provide greater credibility to the multicriteria method developed in evaluation of the service.

The motivation for choosing the Fuzzy Set is based on the data processing mode since the fuzzy numbers simplify the expression of the human judgment that in it is individual rationality, the translation of the subjectivity of the individual and the processing of data [22]. The choice of TOPSIS for the possibility of ordering variables by means of comparison with the perfect alternative. The use of the aggregated techniques was adequate since the gain was obtained to analyze the quality in the service in the most reliable way to its reality, as well as to capture subjective aspects not evaluated by the traditional methods in the crisp scale.

This work is structured in 5 sections. The next section is the literature review. In Sect. 3 the proposed steps for service evaluation were presented, joining fuzzy systems theory and TOPSIS method. In Sect. 4 the results of the work. Finally, the conclusions drawn from the research findings and their implications are discussed.

2 Literature Review

In this section, it will present the main concepts of this work: The Bus Rapid Transit system concepts; quality in service; the main attributes that should be considered for evaluating the quality of public transport services; the fundamentals of fuzzy systems theory and of the TOPSIS multicriteria method.

2.1 The Bus Rapid Transit System

The BRT is characterized as a faster passenger transport. It has the quality of the rail transportation and the flexibility of the public transportation on a bus system [9, 10]. The BRT System has a great potential for reducing the emission of gases in the atmosphere on urban areas, considering that bus travel accounts for approximately 85% of public travel in Brazilian cities. Compared to conventional bus systems, the BRT can carry a much larger number of passengers, it reduces fuel consumption per passenger and per kilometer. As BRT vehicles use exclusive lanes [23].

The BRT system has performance and comfort characteristics like a modern rail transport system, but at a fraction of the cost. A BRT system usually costs between 4 and 20 times less than a tram or light rail vehicle (VLT) system, or 10–100 times less than a subway system [24]. The characteristics adopted for the full operation of the BRT system, according to the National Public Transport Association (ANTP), follow the definitions:

- Exclusive track;
- Use of the central bed, or sidewalk, or counter flow;
- Range of approximately 3.5 m wide;
- Boarding/disembarking stations between 2.5 and 5.0 m;
- Overtaking range in stations at least 20 m wide, exclusively for BRT.
- Average speed of 23–30 km/h.

Another peculiarity of the BRT, when it was compared to the conventional transportation system, is: provide the user with clear signage, system maps, electronic panels at the stations, releasing important information regarding schedules, lines and stopping points. A trend adopted by several cities in the country, the BRT system aims to attract more passengers, offering more comfort and agility during travel, as is the case of the city of Uberlândia in Minas Gerais, with a little more than 600 thousand inhabitants; it has a corridor of 7.5 km in the Avenida João Naves de Ávila, 6 years ago. In São Paulo, BRT has got a distance of 9.7 km, it is used by 81 thousand passengers. In the city of Rio de Janeiro, the use of BRT transport was paramount for the existence of express and semi-express lines. In the satisfaction survey, the users of these transoeste lines showed 90% satisfaction regarding travel time, according to revised exam [25].

In MRR the BRT system, inaugurated in 2014, is used in a specific region of Greater Recife, being monitored by the Transport Consortium of the Metropolitan (TCM), its lines are divided into East–West and North–South. The North–South Corridor allows the connection of the municipalities of Igarassu, Abreu and Lima, Paulista and Olinda to the Center of Recife. Currently operating with six lines and 25 stations, the corridor meets a demand of 66 thousand users per day [26]. The East–West corridor allows passengers in the Camaragibe municipality to travel to the center of Recife through three BRT lines in operation. This corridor currently has 15 stations in operation and meets a demand of 50 thousand users per day. The expectation is that these number reaches 180 thousand people/day when the corridor is operating in its entirety with eight rows and 26 stations [26].

According to [26], the characteristics of the collective transport adopted in Pernambuco and surrounding cities, unlike the traditional vehicles of collective transportation, would be: air-conditioning (1), rear engine (2), automatic

transmission (3), Which brings more comfort to both the driver and the passengers, the buses have four double doors on the left side (4), with access to the floor level of the vehicle. BRTs also have internal led lighting (5), GPS monitoring (6), communication system with the Operational Control Center (7), sound warning of stops (8), level flooring to the platforms of the stations and terminals (9).

2.2 Quality in Services

According to [27] services are directly or indirectly linked to people's lives and measuring the quality of services provided through customer perception is a challenging proposition within an organization. Thus, measuring quality in service is a complex process, although there are several models for this purpose, because quality is tied to consumer satisfaction, which in turn is given by intangible factors [28]. Differently the evaluation of a product, when the evaluation is centered on the quality characteristics, through the evaluation by attributes or by variables [29], presented or not in the product.

The difficulty in evaluating services can be observed in the literature itself, through oppositions of models by classic authors such as [20] with SERVQUAL, seeking to capture with the client the perception of quality, through the scale created, through a questionnaire structured with the purpose of mapping the consumer's expectations in relation to the sector of the service studied and the perception; [30] with the SERVPERF model, in which their scale was designed to evaluate the performance of the services, using the same items and dimensions of the SERVQUAL model, showing the quality of the service delivery. The difference of this model for the first one is that the quality assessment is performed after the service is provided, that is, the evaluation note is the consumers' own perception [30, 31].

2.3 Quality in Public Transport Services

Quality in services is a complex, diffuse and abstract concept [32]. This is a result of the characteristics of services such as intangibility, heterogeneity, inseparability [20]. The intangibility of services shows that they are abstract, requiring differential treatment in each execution. They are inseparable, since it is not possible to produce or store services in the same way as a product [33]. They are heterogeneous because it is practically impossible to maintain constant quality in view of the fact that they are performed to the extent that they are provided and generally require adjustments to the environment. Finally, they are simultaneous, that is, their production and consumption occur at the same time, the time of delivery occurs with the customer contact [34].

Specifically, when talking about public transport services, many of the previous features are present. This type of service can not be stored because if passengers do not board at certain times, it is not always possible to accommodate them at other times and the service is not provided in its entirety. In addition, each trip can be considered as a specific service (heterogeneity), as it is influenced by several aspects (climatic conditions, traffic conditions, vehicle conditions, number of passengers, several drivers and collectors) [5, 35].

The bus service is provided and consumed collectively and is considered a mass service [36] in which users do not always have the same profile and do not share the same. Even though, in this sense, the quality of service when associated to the level of comfort, noise, temperature, etc., being able to have different meanings among the passengers, possessing a certain level of subjectivity. However, most of the time the payment is made before the service is provided, which usually does not allow the user to give up the service [35].

Thus, considering the dimensions of the SERVQUAL model proposed by [20] and the attributes considered important in the literature on quality in collective transport, the dimensions and variables that will be assumed by the approach proposed in this work are presented in Table 1.

As shown in Table 1, seven dimensions were constructed for quality assessment. Among them are those more related to tangible aspects such as comfort, convenience, Technical Security, and others related to the human element with empathy and communication. The identification of the attributes and their corresponding characteristics serve as a basis for an evaluation of the quality of service in the transport and for obtaining a quality transport service. Thus, the seven dimensions presented in Table 1 will be used to evaluate the services offered by the BRT system in MRR, considering that they encompass the entire service cycle offered from embarkation to landing.

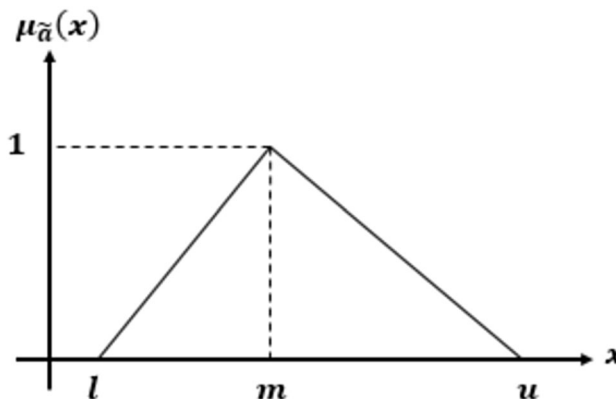
2.4 Fuzzy Systems Theory

The traditional logic of mathematical sets has as its essence the dichotomy of pertinence of the elements it belongs or does not belong to a given set, only these possibilities exist. However, in the real world there are situations that, in the absence of complete information, become ambiguous and/or vague, not being circumvented by traditional mathematical logic. This is often the case in the use of linguistic terms, such as in the case of a satisfaction survey, terms such as “good,” “satisfactory” and “poor” can be used to evaluate the service [37].

In this context, in 1965, Zadeh publishes the article Fuzzy Sets, approaching the mathematical rigor to the inaccuracies of the real world. Fuzzy logic, as it is called, is

an extension of Boolean logic and allows an element to belong to one or more sets, or not, in varying degrees. Thus, the fuzzy logic is defined as a fuzzy set A , of the universal set U , by means of the membership function $\mu_A(x)$, with all its values within a range $[0,1]$, which conforms Eq. 1 [38].

$$\mu_A : U \rightarrow [0, 1] \tag{1}$$



In these terms, while in the traditional logic one has that $f(x) = 0$ if, and only if, $x \in A$ and $f(x) = 1$ if, and only if, $x \notin A$ in fuzzy logic has $f(x) = 0$ if, and only if, $x \in A$; $f(x) = 1$ if, and only if, $x \notin A$ and $0 \leq \mu_A(x) \leq 1$. Thus, an element belongs to a set with a certain degree of pertinence, so that a certain sentence may be partially true and partially false. Moreover, the same element may have degrees of pertinence other than 0 for more than one fuzzy set.

As in traditional logic, fuzzy logic can be expressed by numbers, which in this case are called fuzzy numbers that can be associated with linguistic terms. There are many types of existing fuzzy numbers, which are generally referred to by the format of their respective membership functions and represent diverse concepts or events. In this work will be presented the fuzzy triangular number, since it will be object of use in the same one. Knowing that \tilde{a}_{ij} is a fuzzy triangular number such that $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$. This fuzzy number is given by the function $\mu_{\tilde{a}}(x)$ which follows the properties described below.

$$\mu_{\tilde{a}}(x) = \begin{cases} \frac{x-l}{m-l}, & l \leq x \leq m \\ \frac{u-x}{u-m}, & m \leq x \leq u \\ 0, & x < l \text{ ou } x > u \end{cases} \tag{2}$$

where m is the modal value of the judgment of criterion i with respect to criterion j , l its lowest possible value and u its maximum value. Note that this number is defined by two linear functions, one that describes the left side of m of

Table 1 Dimensions and variables of the quality of public transport services

Dimensions	Variables	References
D1 reliability	V01. Fulfillment of travel times	[54, 55]
	V02. Presence of line schedules at stopping points	
	V03. Safe driving of vehicles	
D2 comfort	V04. Presence of new and comfortable vehicles	[18, 19, 55, 56]
	V05. Vehicles with low noise/internal noise	
	V06. Air-conditioning working properly	
	V07. Comfort of stopping points	
D3 convenience	V08. Single ticket charging for the integrated transport service	[15, 17–19]
	V09. Easy parking near stopping points	
	V10. Existence of free Internet in the vehicles and stopping point	
	V11. Existence of shops and convenience services near stopping points	
D4 communication/information systems	V12. Telephone information on schedules and routing of the lines	[13, 14, 29]
	V13. Respond to user questions in a timely manner	
	V14. Availability of transport service information over the internet	
	V15. Existence of campaigns to use the public transport service	
D5 technical security	V16. Driving vehicles with a safe speed	[16, 17]
	V17. Stop the vehicles at stop points only	
	V18. Presence of safety equipment in vehicles	
D6 accessibility	V19. Presence of sidewalks and bicycle paths near the stopping points	[35, 54–57]
	V20. Existence of facility to access the transport service	
	V21. Existence of physical structures adapted for those with special needs to access the transport service	
D7 empathy	V22. Friendly attitude of the staff	[18, 29, 56]
	V23. Attitude of employees demonstrates their willingness to help me	
	V24. User needs are quickly answered by employees	

the triangular fuzzy number (being monotonically increasing) and the other one that describes the right side of m (being monotonically decreasing). As in traditional mathematical logic, some operations with triangular fuzzy numbers can be performed, for example, given the triangular fuzzy numbers $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ it has:

$$\text{Addition : } M_1 \oplus M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (3)$$

$$\text{Multiplication : } M_1 \otimes M_2 = (l_1 \cdot l_2, m_1 \cdot m_2, u_1 \cdot u_2) \quad (4)$$

$$\text{Division : } M_1/M_2 = (l_1/l_2, m_1/m_2, u_1/u_2) \quad (5)$$

Division by a real number:

$$M_1/x = (l_1/x, m_1/x, u_1/x) \quad (6)$$

$$\text{Inverse : } M_1^{-1} = (l_1, m_1, u_1)^{-1} \approx (1/u_1, 1/m_1, 1/l_1) \quad (7)$$

According to [22], it is possible to perform a defuzzification process, which consists in transforming the value of the linguistic variable processed by the fuzzy logic into a discrete value, that is, to convert the value Fuzzy number referring to the output of the inference to the universe of

real numbers, since some applications of the fuzzy number need this treatment. Among the various methods for carrying out this process, the following equation was used for this purpose in this research.

$$\text{No Crisp} = \frac{(l_1 + 2m_1 + u_1)}{6} \quad (8)$$

From Eq. 8, it is possible to establish a comparison between a set of variables or dimensions of real numbers. This allows for comparability between service dimension assessments.

It is possible to verify the use of Fuzzy Systems Theory for quality evaluation in some recent works such as [39] who proposed a Fuzzy Analytic approach to the measurement of service quality integrating the Servqual, Fuzzy analytic hierarchy process (FAHP) and the Fuzzy Analytical Network Process (FANP) in a Taiwanese commercial bank. The results of the work showed that the quality of the service is composed of the skills, accessibility, and tangibility of the employees.

Hsu [40] has developed a fuzzy multiple-criteria decision-making model combining the fuzzy ANP, the fuzzy

VIsekriterijumska optimizacija i KOMpromisno Resenje (VIKOR) and the importance-performance analysis (IPA) methods to analyze the customer gaps by considering customer preferences, customer perceptions, and customer expectations simultaneously. The proposed model was applied at a cinema in Taiwan. The results show that clients believe that the “Responsiveness” dimension is the most important, followed by “Reliability,” “Tangibility,” “Assurance” and “Empathy.”

Tooranloo and Ayatollah [41] proposed an approach to diagnosing the quality of Internet banking service with failure analysis and its effects on the intuitionistic fuzzy environment in Iranian Banks. The authors identified 20 items of failure in the quality of the e-banking service that was prioritized by the TOPSIS technique and the failure-effect mode analysis (FMEA) model. The results indicate that the item of not protecting data sent by the user through the bank’s online banking application security tools has the highest priority in the failure of Internet Banking quality programs.

Mishra et al. [42] developed an approach to classify the quality of service provided in four vehicle insurers using intuitionistic fuzzy weighted information measure. The result of the insurers’ assessment reveals that ICICI Lombard has the highest rating on quality of service and this ranking is in line with the survey conducted by the Consumer Satisfaction Index of Automobile Insurance in 2010 in India. In addition, the gap between the perception and expectation of ICICI Lombard customers is the smallest among the four vehicle insurers.

Xu et al. [43] proposed a method to evaluate service quality based on the use of hesitant fuzzy linguistic term sets in an online shopping mall in China. According to the results of the evaluation, the authors concluded that the company studied did not provide a satisfactory service to its customers, and it is the overall quality of service is not ideal. Among the dimensions analyzed, Reliability was the one that obtained the best performance (Slightly Good), following by the dimension of empathy (Middle). The outcome of the quality assessment for the Tangibles, Convenience and Responsiveness dimensions was Slightly Poor.

As demonstrated throughout this paper there are some applications of fuzzy systems theory to evaluate the quality in some types of services, but the application of the theory of fuzzy systems in the public transport sector, in particular, the BRT System, is still incipient, being necessary this type of study.

2.5 Technique for Order Performance by Similarity to Ideal Solution: TOPSIS

TOPSIS is a method that evaluates the performance of alternatives of a problem with respect to an ideal point and an anti-ideal point [44]. The logic behind TOPSIS is to define the optimal solution and the negative solution. The ideal solution is the solution that maximizes the benefit criteria and minimizes the cost criteria, while the negative solution is the solution that maximizes the cost criteria and minimizes the benefit criteria [45]. In sum, the ideal solution consists of all the best achievable criteria values, while the negative solution is composed of all the worst achievable criteria values. Consequently, the optimal alternative is that which has the shortest distance from the ideal solution and the farthest distance from the negative solution [45].

The TOPSIS method has been used by several authors in public transport, for example, [46] used this method associated with fuzzy logic and the GRA multicriteria method to evaluate the satisfaction of public transport users in the city of Istanbul. [47] also made use of TOPSIS to assess the quality of public transport services in the city of Salaam, Tanzania.

As it is perceived this method has been used along with other techniques, such as statistics and multicriteria, for example, or modifications in the genesis are performed to obtain results more robust or more adaptable to the reality of the data available. In this work it used an extension of the TOPSIS method proposed by [45, 48] for group decisions. Through this extension, the authors insert the fuzzy numbers in the structuring of the TOPSIS method, aiming at ordering the alternatives [37]. This proposed structure will be described in Sect. 3 of this paper.

3 Materials and Methods

In this section, the Case Study, Data Collection and the steps of the proposed approach will be presented.

3.1 Case Study and Data Collection

This work can be classified as applied research since it was sought to evaluate the quality of the service provided by the BRT system in the northeastern region of Brazil. Regarding the classification, according to the object, this work is exploratory and descriptive, because the quality phenomenon was investigated through the application of a questionnaire collected according to the convenience of the researchers, being made available the online questionnaire through social networks.

According to [49, 50] in recent years the academic research carried out through social networks has been increasing among researchers due to lower costs in data collection, speed of response and convenience of the response time and place.

In addition, the research is classified as a case study since it seeks to empirically investigate a contemporary phenomenon within its real-life context, in this case, the situation experienced by users of BRT in the state of Pernambuco, northeast region of Brazil. Thus, the sample size was composed by simple random sampling [51], according to Eqs. 1 and 2:

$$n_0 = \frac{1}{E_0^2} \tag{9}$$

$$n = \frac{Nn_0}{N + n_0} \tag{10}$$

By means of Eq. 9, it had an initial approximation of the sample (n_0), where an unknown population is considered, with a statistical significance level of 95% and population variance for the case of greater population heterogeneity (proportion of the event of 0.5). In this research, an error of 5% (E_0), was admitted, which generated an initial sample of 400 people. The value of the tolerated sample error of 5% was considered by the researchers, since the smaller the sample size, the larger the sample needed to serve it.

Equation 10 adjusted the sample size for the population of this study. Considering that the average daily demand for the BRT system in Recife is around 500.000 (five hundred thousand) passengers, for the first 6 months of 2017, according to data from [11], a sample (n) of 399.68 was obtained. Based on these estimators, the sample of this research was 569 passengers.

The data collection instrument, the questionnaire (“Appendix 1”), was elaborated taking into account the five dimensions proposed by the SERVQUAL model and two dimensions considered important in the literature on quality in public transport.

The questionnaire applied to users of the BRT system was composed of two parts. The first part consists of the collection of basic information regarding sex, age, level of education and current occupation. The second one sought to evaluate the user’s perception through the 24 questions related to customer satisfaction in the service received (Table 1). These 24 questions relate to seven dimensions of quality. They are: Reliability, comfort, Convenience, Communication/Information Systems, Technical Security, Accessibility and Empathy. Such dimensions were measured from the Likert scale [52] from 1 to 5, where 1 Very Dissatisfied, 2-Dissatisfied, 3-Indifferent, 4 Satisfied and 5 Very Satisfied.

3.2 The Proposed Approach

This section aims to present the proposed approach, whose objective is to evaluate the quality of public transport services offered to users of the BRT system. From this, some steps have been followed to achieve, they are described below and illustrated in Fig. 1.

The methodological steps used to evaluate the quality of the services offered by the BRT system are described below.

Step 1 Data collection with users of the BRT service: In this step, the data were collected from users of the BRT system in the MRR, the sample was composed of 569 users from several neighborhoods of this locality. The questionnaires were applied during a month in the year 2017 and were composed of 24 variables that comprise seven dimensions, according to the theoretical framework presented in Table 1. The data were collected through an online platform available to users of the service studied. To measure the level of satisfaction in relation to the studied variables, linguistic terms were used with five levels of user satisfaction in front of the service provided by public transport companies, from Very Dissatisfied to Very Satisfied.

Step 2 Fuzzification of linguistic terms: To measure the level of quality of services provided, linguistic terms were used, as previously presented. To reduce the subjectivity of the evaluation in the data analysis, the linguistic terms were used through the fuzzification process, that is, for each linguistic term was associated with a triangular fuzzy number as shown in Fig. 2. The triangular numbers used, distributed between zero and ten.

Step 3 Aggregation of individual responses: As the BRT services were analyzed by 569 people, to create a single triangular fuzzy number for each variable, the fuzzified assessments of each user were aggregated, according to [37, 48], according to Eq. 11.

$$\begin{aligned}
 M &= (l_1, m_1, u_1) \\
 &= \frac{1}{n} \oplus (M_1 \oplus M_2 \oplus \dots \oplus M_n) \\
 &= \left\{ \frac{\sum_{i=1}^n l_1^{(i)}, \sum_{i=1}^n m_1^{(i)}, \sum_{i=1}^n u_1^{(i)}}{n} \right\}
 \end{aligned} \tag{11}$$

where M is the global value of each fuzzy set of evaluation of BRT users (n) for the variable z . By means of this operator, the individual evaluations for each analyzed variable are aggregated in global evaluations [37].

Step 4 Evaluation of fuzzy numbers: In this step, the aggregate triangular numbers obtained for each variable of this research were evaluated, based on the scale used, by means of the parameter m of the resulting triangular number. To do this, the following scale will be used for

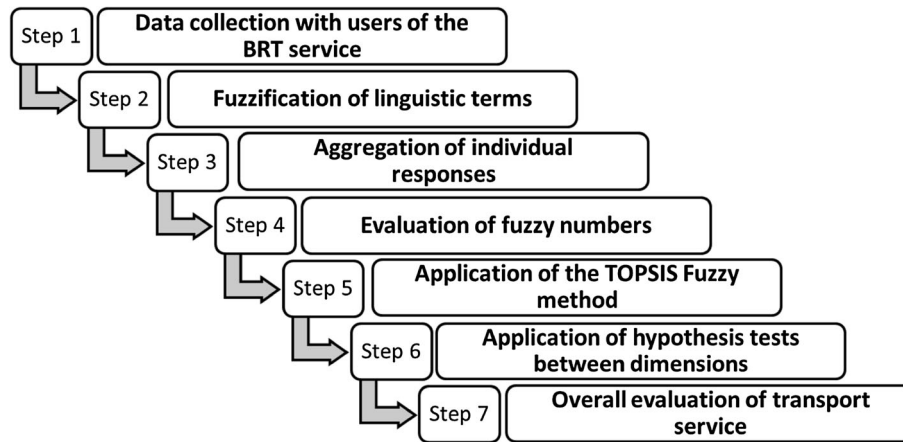


Fig. 1 Macro-methodological steps used for quality assessment

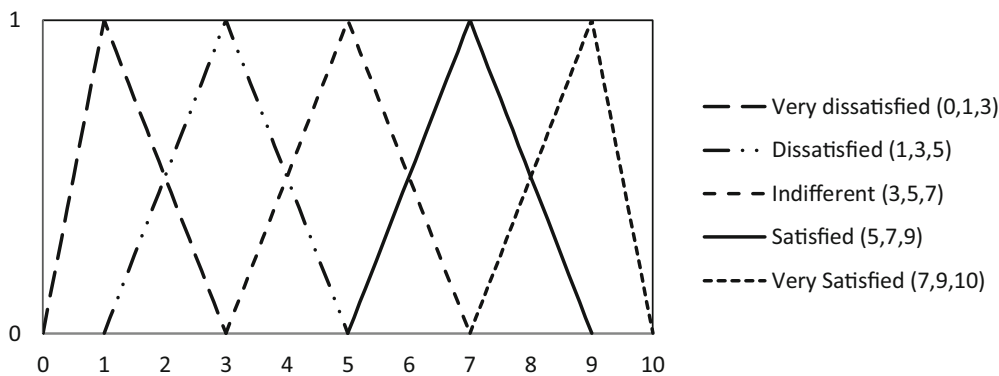


Fig. 2 Representation of the fuzzification of the linguistic terms used in the research

evaluation: 0–2 as a very bad evaluation, 2–4 a bad evaluation, 4–6 a regular evaluation, 6–8 a good evaluation and, 8–10 an excellent evaluation of the service.

Step 5 Application of the TOPSIS Fuzzy method: After obtaining the average fuzzy evaluation of each variable, an extension of the TOPSIS method proposed by [45, 48] was applied. For this, four sub-steps were followed to obtain an ordering of the variables, according to the ideal and anti-ideal solutions. They are described below:

Step 5.1 Determination of the optimal and negative fuzzy solutions. The optimal is given by Eq. 12 and the negative solution is represented by Eq. 13.

$$A^+ = \{ (\max V_{ijj \in J}), (\min V_{ijj \in J'}), \quad i = 1, 2, 3, \dots, m \} \tag{12}$$

$$A^- = \{ (\min V_{ijj \in J}), (\max V_{ijj \in J'}), \quad i = 1, 2, 3, \dots, m \} \tag{13}$$

The ideal solutions represent the maximum and minimum evaluations of the offered services. In the case of the optimal, when the conditions in which the service offered by the BRT meet users' expectations, leaving them

extremely satisfied ($A^+ = \{7, 9, 10\}$), this solution must be typical of organizations that Seek excellence in service delivery. On the other hand, the negative solution is the one in which the service leaves great gaps between the expectation and the perception of the users, thus generating great customer dissatisfaction ($A^- = \{0, 1, 3\}$), this is the worst performance the organization can have, in which case there is no loyalty and a lasting relationship with external customers. The establishment of these ideal solutions in the TOPSIS method is important because they serve as reference points for ordering the evaluations, considering the distances that an evaluation has of an ideal and anti-ideal service [37, 45, 47, 48].

Step 5.2 Determination of the euclidean distance of fuzzy evaluations. After determining the ideal solutions, it is possible to calculate the Euclidean distance of each variable with respect to the optimal and negative solutions (Eqs. 14 and 15). This measure represents how distant it is to the evaluation of the variable z of that evaluation considered maximum and minimum, revealing gaps in the service rendering [45, 48].

$$d^+(V_{ij}, A_j^+) = \left[\frac{(a_1^+ - l_1)^2 + (a_2^+ - m_2)^2 + (a_3^+ - u_3)^2}{3} \right]^{1/2} \tag{14}$$

$$d^-(V_{ij}, A_j^-) = \left[\frac{(a_1^- - l_1)^2 + (a_2^- - m_2)^2 + (a_3^- - u_3)^2}{3} \right]^{1/2} \tag{15}$$

Step 5.3 Calculation of sums of Euclidean distances. The Euclidean distances can be summed to obtain the distance of the service delivery dimensions, they are expressed by Eqs. 16 and 17 [37, 45, 48].

$$S_i^+ = \sum_{j=1}^n d^+(V_{ij}, A_j^+) \quad \text{com } i = 1, \dots, m; \tag{16}$$

$$S_i^- = \sum_{j=1}^n d^-(V_{ij}, A_j^-) \quad \text{com } i = 1, \dots, m; \tag{17}$$

Step 5.4 Calculation of the relative proximity to the ideal solution of each attribute. In this step, the ordinations of each variable are obtained based on their distances from the ideal solutions (Eq. 18).

$$C_i = \frac{S_i^-}{(S_i^+ + S_i^-)} \quad \text{com } i = 1, \dots, m \quad eC_i \in [0, 1] \tag{18}$$

From the values of alternative C_i are classified, where an alternative with high value of C_i has a shorter distance from the ideal solution and further from the anti-ideal solution. Thus, it was possible to establish an ordering between the evaluations of variables and dimensions studied in this study, listing the positive and negative points that users have experienced in the use of BRT services.

Step 6 Application of hypothesis tests between dimensions: After applying the four sub-steps of Step 5 concerning the extension of the TOPSIS method, it was possible to obtain rates for each variable and dimensions studied, which ordered them. To verify if the rates generated by the multicriteria method came from the same probability distribution, and consequently, if the rates were statistically equal, the following steps were followed: (1) The variables were aggregated into dimensions according to Eq. 11 and according to the correspondence shown in Table 1; (2) Then, each aggregate individual evaluation is defuzzified by means of Eq. 8. It was possible to obtain a crisp number representing the evaluation of each user for each one of the analyzed dimensions, serving as input for the hypothesis tests; (3) With the series formed for each dimension, the Kolmogorov–Smirnov test was used to verify if the data of each dimension had a normal probability distribution or not. If the data were parametric the

hypothesis test used was the t test, otherwise the Mann–Whitney test would be used. This step was important because it provides a statistical analysis of the orders obtained in the past, respecting the probability distribution of the input data and seeking greater quality and reliability of the tests. The accomplishment of this stage aimed to provide greater credibility to the multicriteria method developed in the evaluation of the service.

Step 7 Overall evaluation of transport service: Based on the ordering obtained in the TOPSIS fuzzy method, for the dimensions and variables, and in the hypothesis tests, the services offered by the BRT system were evaluated considering the impact of each variable in the dimension and their statistical differences between them.

From the steps described above it is believed that a systematic evaluation of the quality of the services offered is possible, respecting the complexity, abstraction and heterogeneity present at the heart of this type of service. With the inclusion of fuzzy logic in the TOPSIS method it was possible to insert the uncertainty in the evaluation and through aggregation (Eq. 11) the heterogeneity of the perceptions of the services were aligned for an overall evaluation. Additionally, the statistical tests allowed us to verify if the weights obtained by the multicriteria model were significantly different or not, provoking an approximation or distance from the importance of the seven analyzed dimensions, from the ideal evaluations and anti-ideas.

4 Results and Discussion

In this section, it will present the results obtained in this research, according to the seven steps described in the methodology.

4.1 Step 1: Data Collection with Users of the BRT Service

The sample of this study was composed of 569 users who use daily the services of BRT lines that operate in the MRR. Of this total, 48.52% were male and 51.48% female. Where approximately 90% were enrolled in higher or postgraduate education. Still, about professional occupation, it was possible to identify that 40.3% studied and/or interned and 35% already worked in public or private organizations. It was also possible to identify that, on average, the users interviewed used six times the BRT system per week (with a standard deviation of 3.93). This information reveals how stratified was the sample of this study, analyzing the evaluations of the service of people who use it eventually and permanently to get around to carrying out their external activities. This stratification was

also reflected from the points at which users start the service life cycle, since they reside in 80 different neighborhoods of the RMR. As transport has at its core the variables time and distance, the proximity and/or distance of the shipments and landings can impact the perception of the quality of the service in a differentiated way.

4.2 Step 2: Fuzzification of Linguistic Terms

For each language term, a fuzzy triangular number was established as established in the methodology of this work, thus it has: 1- Very Dissatisfied (0,1,3), 2- Dissatisfied (1,3,5), 3- Indifferent (3,5,7), 4- Satisfied (5,7,9) and 5- Very Satisfied (7,9,10).

4.3 Steps 3 and 4: Aggregation of Individual Responses and Evaluation of Fuzzy Numbers

Initially it was possible to obtain the aggregation of fuzzified evaluations of the users, according to Eq. 11. From Table 2, it is observed that the variable V17 was that presented the largest modal value of the fuzzy number,

while the V2 was the least punctuated in the fuzzy evaluation.

From Table 2 and the fuzzy scale used in this research, the aggregated fuzzy evaluation was contrasted with the scale used. Thus, it was possible to identify that, among the studied variables, the users considered the service between good and bad, and there were no considerations of a service that left satisfied, very satisfied or dissatisfied, that is, a poor or excellent service in the extremes. In the light of the analyzed variables and dimensions, the communication dimension (D4) presented several variables with the highest number of evaluations between bad and regular. This reflects the lack of communicative technological tools to convey to user's information and innovations about the service. Another relevant point is that public transport services need to provide users with real-time information on integrated terminals and BRT stations on travel times, traffic and road conditions, to use them for alternative routes; to help their routes, the integrated transport system can be used, ensuring that users reach their destinations in a timely manner.

The convenience dimension (D3) also presented variables evaluated with a large percentage of bad service, the

Table 2 Fuzzy numbers of the studied variables

Dimensions	Variables	Fuzzy numbers			Fuzzy evaluation
		<i>l</i>	<i>m</i>	<i>u</i>	
D1	V1	3.0237	4.8343	6.7396	Regular
	V2	1.3077	2.7870	4.7574	Bad
	V3	3.8698	5.7574	7.5740	Regular
D2	V4	4.4615	6.3846	8.0710	Good
	V5	4.2840	6.1834	7.8994	Good
	V6	3.9172	5.8047	7.5680	Regular
	V7	2.2249	3.8757	5.8107	Bad
D3	V8	4.7101	6.5976	8.1361	Good
	V9	2.0118	3.6036	5.5385	Bad
	V10	2.1420	3.8757	5.8107	Bad
	V11	1.5621	3.1420	5.1065	Bad
D4	V12	1.9527	3.5444	5.4793	Bad
	V13	1.9349	3.6509	5.6331	Bad
	V14	3.0651	4.9053	6.7751	Regular
	V15	1.8935	3.4970	5.4438	Bad
D5	V16	4.4260	6.3491	8.0828	Good
	V17	5.6213	7.5799	9.0059	Good
	V18	2.8107	4.6568	6.5562	Regular
D6	V19	2.2308	3.9704	5.8994	Regular
	V20	3.1598	4.9645	6.8225	Regular
	V21	3.9763	5.8757	7.6272	Regular
D7	V22	3.3669	5.2959	7.2130	Regular
	V23	3.1065	5.0000	6.9053	Regular
	V24	2.8994	4.7633	6.6805	Regular

highlight of this dimension was the fact that users consider with good the fact that the integrated transport system only charges a fee for the use of several lines. This is not to say that users are satisfied or not with the price currently charged, but they value the fact that a single tariff is charged for the variety of bus lines that can be used in the MRR.

Still, the dimensions of Technical Security (D5) and comfort (D2) were those that presented a greater number of variables with good ratings. The other dimensions had an average evaluation considered with regular, finding that the attributes of the service in them met the minimum requirements of the users. After the evaluation of the attributes of the service quality through the variables, for a macro-level analysis it was possible to aggregate them according to the dimensions to which they belonged. In this way, it was possible to obtain the fuzzy triangular numbers of each dimension and their corresponding evaluation. The results of the dimensions are described in Table 3 and exemplified by the Reliability (D1) dimension in Fig. 3.

Through Table 3, it is possible to observe that no dimension was evaluated as very bad or very good demonstrating that the BRT service is not considered as excellence by the users, having several gaps that must be studied and improved to meet the BRT services standard presented by Cities of Bangkok [7], Beijing [5] and Sydney [8]. Even so, among the dimensions studied in this research, the one that presented a better fuzzy evaluation was the Technical Security and the worse was in the Communication/Information Systems. The others presented an evaluation considered as regular, by the scale used. Searching for an evaluation of the service referenced by its worst and best evaluation, the following is the results of the application of an extension of the TOPSIS fuzzy method. Figure 3, through the graphic representation, confirms the evaluation identified in Table 3. Figure 4

presents a dimensional illustration through the radar graph of the fuzzy evaluation results.

4.4 Step 5: Application of the TOPSIS Fuzzy Method

From the optimal solution ($A^+ = \{7, 9, 10\}$) and the negative solution ($A^- = \{0, 1, 3\}$), according to the fuzzy scale used, the users' Euclidean distances for each variable are calculated according to Eqs. 14 and 15 (Table 4). Then, using Eqs. 16, 17 and 18, it was possible to order the evaluations of the variables surveyed under the users' vision (Table 4).

As a reflection of the aggregated fuzzy numbers of Table 2, the variable V17 presented better performance in the evaluation of the service by the users. This is a reflection of the fact that although the BRT system currently operates with two types of doors, those that allow embarkation and disembarkation on the right as the traditional buses and those located on the left for people movements in the exclusive stations of the BRT vehicles in the central Vehicles are only allowed to board and disembark at the exclusive stations of the central bed, which are installed in places that maximize the uninterrupted movement of vehicles and stop at the strategic points of the cities, thus, users gain greater agility in their displacement and, consequently, the quality perceived by the system increases.

A second important factor in ordering is the collection of a single tariff for the use of public transport of different types (V8), for example, BRT × subway × traditional bus system and its combinations [5, 16]. Two actions of the companies and the state government impact on this variable. The first was the integration of the BRT system, which took place in 2014, with the integrated structural system (ISS) of passengers that already existed in the RMR. The ISS is geared toward mass transport and presents a spatial configuration consisting of radial and perimetric axes. At the intersection of these two axes, there are the integration terminals that allow the user to change the line without paying a new tariff. Access from the suburb to the integration terminals is via the feeder lines. Altogether, there are 10 operating companies, responsible for 185 lines, of which 123 are feeder, 3 perimeters, 24 trunks, 18 inter-terminals, 6 transverse and 11 circulars, serving 10 of 14 municipalities of the MRR.

The second action was the implementation of metropolitan electronic coupons (MECs) that serve as an exclusive means of entry into the BRT stations. From MEC came the concept of "temporal integration" that allows the user to use other conventional bus lines, at certain points along the stretch that the BRT passes and does not have

Table 3 Fuzzy numbers of the dimensions

Dimensions	Fuzzy numbers			Fuzzy evaluation
	<i>l</i>	<i>m</i>	<i>u</i>	
D1	2.733728	4.459566	6.357002	Regular (R)
D2	3.721893	5.562130	7.337278	Regular (R)
D3	2.606509	4.304734	6.147929	Regular (R)
D4	2.211538	3.899408	5.832840	Bad (B)
D5	4.285996	6.195266	7.881657	Good (G)
D6	3.122288	4.936884	6.783037	Regular (R)
D7	3.124260	5.019724	6.932939	Regular (R)

Subtitle: Very Good (VG), Very Bad (VB)

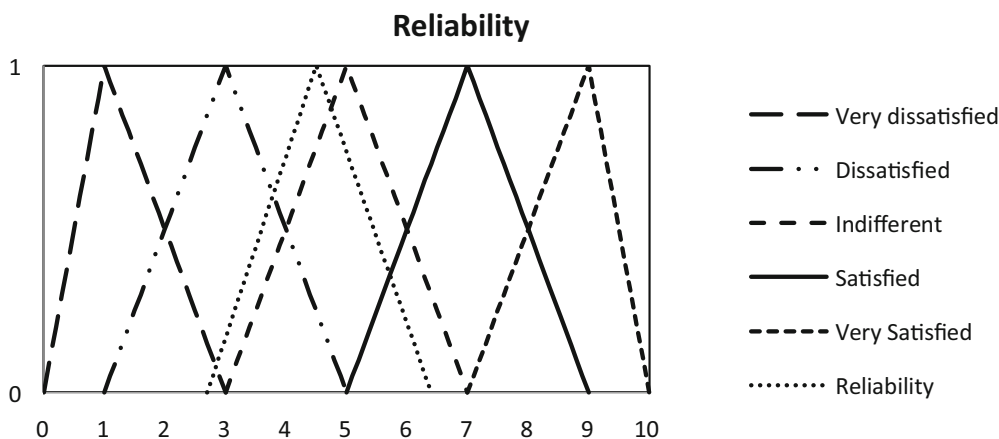


Fig. 3 Fuzzy triangular numbers of the reliability dimension

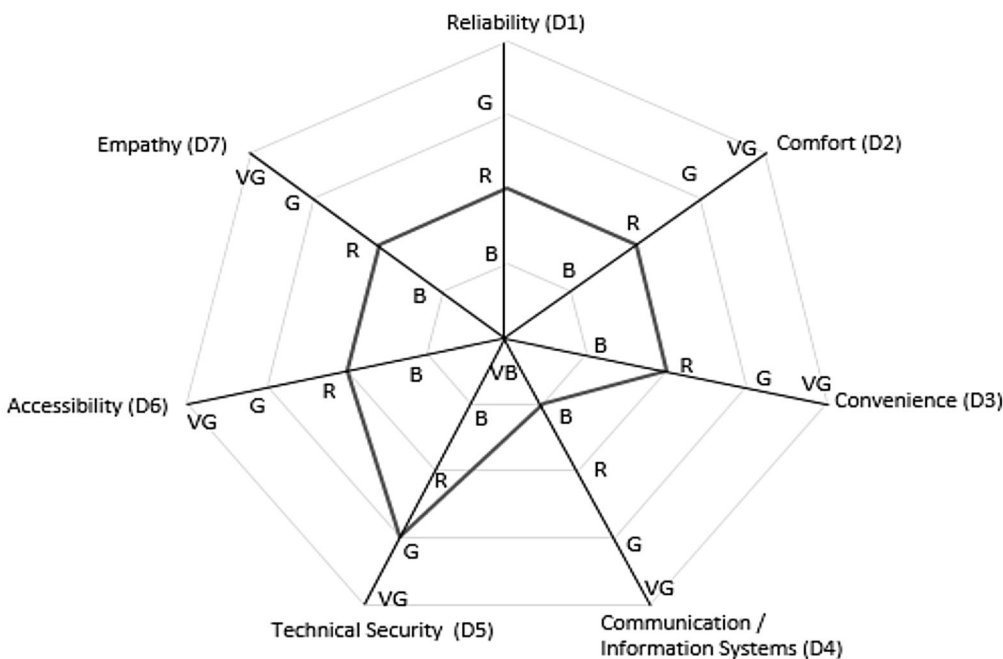


Fig. 4 Radar chart for fuzzy evaluation results of dimensions

nearby integrated terminals, with the payment of a single passage in the maximum period of 2 h.

In the other vertex are the variables V2 and V11 that showed greater proximity to the negative solution, that is, a higher level of service dissatisfaction. Among the variables studied, the greatest source of dissatisfaction is related to the availability of information on the forecast of departure times of the BRT lines in the integrated terminals and the arrival times of the vehicles in the exclusive stations in real time. It should be noted that integrated terminals and exclusive stations have equipment for the transmission of this information and even an information system was created for this purpose, but most of the time this service does not work. Without the predicted arrival of the vehicles in

the stations, the psychological wait time is extended beyond normal chronological time, causing the perception of quality by the users to decrease considerably. Another variable that contributes to this decrease is the absence of shops and convenience services near the vehicle stops (V11). This is due to the system is not operating at full capacity, making the vehicles do not stop at large moving points of people.

When it aggregated the analysis of the services offered, the evaluations were aggregated into dimensions and their Euclidean distances are represented in Table 5. From these distances, it ordered the dimensions. The Technical Security dimension (0.6520) was the one that presented the closest proximity to a service of excellence, revealing that

Table 4 Euclidean distances and ordering of variables according to TOPSIS technique

Variables	$d^+(V_{ij}, A_j^+)$	$d^-(V_{ij}, A_j^-)$	Ranking (°)	C_i	Variables	$d^+(V_{ij}, A_j^+)$	$d^-(V_{ij}, A_j^-)$	Ranking (°)	C_i
V17	1.2787	6.0818	1	0.8263	V1	3.8207	3.5510	13	0.4817
V8	2.1976	5.1606	2	0.7013	V24	3.9065	3.4696	14	0.4704
V4	2.3808	4.9871	3	0.6769	V18	4.0113	3.3624	15	0.4560
V16	2.4033	4.9678	4	0.6740	V19	4.6496	2.7206	16	0.3691
V5	2.5639	4.8036	5	0.6520	V7	4.7120	2.6532	17	0.3602
V21	2.8597	4.5090	6	0.6119	V10	4.7402	2.6304	18	0.3569
V6	2.9227	4.4458	7	0.6033	V13	4.9442	2.4292	19	0.3295
V3	2.9551	4.4169	8	0.5991	V9	4.9634	2.3992	20	0.3259
V22	3.4003	3.9807	9	0.5393	V12	5.0224	2.3404	21	0.3179
V23	3.6849	3.6924	10	0.5005	V15	5.0701	2.2943	22	0.3115
V20	3.7026	3.6657	11	0.4975	V11	5.4108	1.9549	23	0.2654
V14	3.7704	3.6008	12	0.4885	V2	5.7297	1.6321	24	0.2217

Table 5 Euclidean distances and ordering of dimensions according to TOPSIS technique

Dimensions	$d^+(V_{ij}, A_j^+)$	$d^-(V_{ij}, A_j^-)$	C_i	Ranking (°)
D1	4.166855	3.199548	0.4343	5
D2	3.144043	4.222065	0.5731	2
D3	4.327691	3.034502	0.4123	6
D4	4.701440	2.665987	0.3619	7
D5	2.563833	4.802469	0.6520	1
D6	3.736951	3.631304	0.4928	4
D7	3.663824	3.714260	0.5034	3

this item was the most evaluated by the users, with variable V17 (0.8263) contributing considerably to the performance of this dimension. The Technical Security analyzed reveals the importance of complying with the principles of the BRT system, such as: presence of safety equipment for emergencies, stopping at staging points alone and driving at a safe speed on the exclusive roads (between 23 and 30 km/h). Regarding the last two aspects presented above, a safety locomotion can help the provision of an agile service.

These are aspects that should be minimally considered by public transport services [53], obeying legal and technical standards of Brazilian legislation for service safety, for example Law No. 12.587, of January 3, 2012, which establishes the directives of the national policy of urban mobility, including collective bus transportation. In theory, this dimension (D5) is not what characterizes the primary benefits of implementing the BRT system but contributes indirectly to service improvement. The high evaluation of

the technical dimension is consistent with the work of [16, 17] that identified a positive relation between security and the general quality of the service.

In second position, the comfort dimension (0.5731) was the best evaluated, although it was considered as a regular evaluation, as demonstrated in the previous topic by the aggregation of its fuzzy evaluation. This demonstrates the personal comfort of the passenger on the BRT and as they await their arrival at the exclusive stations through the availability of a suitable temperature, a comfortable seat for long distances, absence of noise, a clean internal environment adds value to the Service and can impact users' satisfaction [14, 15]. The great importance of this dimension in the public transport sector, especially for BRTs, is related to state-of-the-art equipment and its conservation, facilities that provide increased comfort for customers, infrastructure and security that give credibility to the tangible aspects of and the performance of this service that directly or indirectly influences the structuring of the other factors and the perceived global quality [20].

On the other hand, Empathy-D7 (0.5034) ranked on a third pace. Although the BRT system reduces contact between employees and users at the front line of the service, users evaluated their contact when it was necessary at some point during the trip, with drivers and helpers present at the exclusive stations along the route and integration terminals. With a fuzzy evaluation also considered as regular, the Accessibility dimension-D6 (0.4928) demonstrated the importance of the services having physical structures that improve the displacement of people, especially those with special needs. For example, access to the exclusive BRT stations is provided by ramps and it has exclusive entrance for special users. In addition, the

vehicles have space reserved for these users, with place for companion and feel safe.

The Reliability dimension-D1 (0.4343) was that which, despite having a variable with the worst individual assessment (V2), ranked fifth among the others. As the BRT system seeks to be characterized by a fast passenger transport that presents the quality of rail transportation and the flexibility of the bus system [10], seeking to mitigate urban mobility problems, it should [54, 55] and to increase the credibility of its users through the length of the travel schedules, since this is one of the most notable characteristics of the public transport service. This may reflect the fact that the system is not yet operating at full capacity, which means that not all of its route presents exclusive tracks, compromising service agility and its credibility. If there is an impact on the credibility of the service, 100% non-functioning of the system also compromises Convenience-D3 (0.4123), since many exclusive stations are not ready, causing shipments and departures from the system to occur far from the starting point or final destination of the users, having compromised the performance of this dimension in the current conditions of the service. On the other hand, the convenience of using the integrated system together with the BRT system means that single tariff charging is a well-assessed item in this dimension, although it is not enough to increase the overall size assessment.

Finally, as a consequence of the fuzzy evaluation, the Communication/Information System dimension-D4 (0.3619) was the one that had the worst overall evaluation, revealing the need for investments in equipment and software for better communication with the users in real time, already that the BRT system seeks to reduce face-to-face contact among users and employees of companies.

4.5 Steps 6 and 7: Application of Hypothesis Tests Between Dimensions and Overall Evaluation of Transport Service

To search the statistical differences between these dimensions, it used a Mann–Whitney test, because the Kolmogorov–Smirnov test reveals that these dimensions not follow a normal statistical distribution (p value < 0.05), the final test results are presented in Table 6.

From the results presented in Table 6, of the combinations performed between the dimensions, two combinations presented statistically equal distributions (p value > 0.05), Reliability–Convenience and Accessibility–Empathy. By the diffuse TOPSIS method the two combinations showed very close weights (0.4343–0.4123 and 0.4928–0.5034), making the hypothesis test validate the results presented by the multicriteria method. This means that of the seven dimensions of service that impact on quality, Reliability

Table 6 Level of significance of the Mann–Whitney test for the evaluation of the dimensions

Dimensions	D1	D2	D3	D4	D5	D6	D7
D1	–						
D2	0.000	–					
D3	0.279	0.000	–				
D4	0.003	0.000	0.031	–			
D5	0.000	0.010	0.000	0.000	–		
D6	0.032	0.001	0.001	0.000	0.000	–	
D7	0.022	0.003	0.000	0.000	0.000	0.773	–

To p value > 0.05 —the two combinations present statistically equal distributions

To p value < 0.05 —the two combinations do not present statistically equal distributions

and comfort have the same ordering and should be considered belonging to the same class, the same thing happens with the accessibility and convenience dimensions. In the decision-making process, considering the variables and data studied in this research, it must consider five dimensions. These can establishment of service improvements.

5 Conclusion

The approach proposed in this work was adequate in its various stages. Initially, the possibility of evaluating the quality of the service provided by the BRT System through the 24 variables and 7 dimensions of quality, using the Theory of fuzzy systems, according to [22], is a clear way to evaluate subjectivity, imprecision and the ambiguity of the client's judgment about the service provided.

Another point that contributes to the appropriateness of the approach is the use of linguistic terms. According to [37] the linguistic terms (Very Dissatisfied, Dissatisfied, Indifferent, Satisfied and Very Satisfied) associated with a fuzzy number tend to also decrease the imprecision of the customer's answers, since the fuzzy triangular numbers overlap enabling a smoother transition between assessments and not part of the classical set theory.

After the quality evaluation, the extension of the TOPSIS technique was used. Thus, the distance between the quality perceived by BRT System users and the ideal service was calculated. The results of the application suggested that the variables best evaluated by the user are technical security and single tariff of collection for use of different public transport, these findings are in convergence with the works of [16–18].

On the other hand, there was a lack of information about the timings of the lines and the presence of convenience

stores, demonstrating that these aspects can be developed for greater user satisfaction. The aggregate analysis of the quality dimensions confirmed that satisfaction with Reliability and/or Technical Security in BRT, and the Comfort obtained during travel and waiting in stations, are the main variables that entail the satisfaction of BRT usage in MRR by the user. However, investments are still needed in the convenience offered to the user, in the Reliability of the service and in the Communication Systems.

Finally, the Mann–Whitney hypothesis test was performed to verify the existence of the statistical difference between the dimensional distributions. From the results of the test, it was verified that the combinations of Reliability–Convenience and Accessibility–Empathy dimensions presented very close weights, thus validating the results presented by the multicriteria method. Thus, in the decision-making process, considering the variables and data studied in this research, five dimensions can be considered in the establishment of service improvements.

5.1 Practical Implications

Among the possible practical implications, it is believed that the proposed approach can contribute to the organization context, as it guides managers and establishes a logical set of procedures to assess service delivery situations, reveals the level of adjustment needed to achieve performance service quality and orders the variables and dimensions of quality by the best performance score according to the customer's perception. Furthermore, with the application of the proposed approach, it is concluded that managers can make the decision to prioritize and/or reaffirm the variables evaluated by the users, obtaining fundamental information for the managerial decision making mainly regarding the specifications to be included in the service for ensuring greater customer satisfaction.

In this way, it is believed that besides contributing as a managerial tool, this study contributes to the social area. The very purpose of BRT's existence can be proven in practice, whose main attraction is the tariff value paid by the user allied to the BRT transport speed. However, it is emphasized that such research reflects the quality perceived by the user in the time and space delimited in the article and that the development of new research can contribute to a better understanding of the object of study.

5.2 Directions for Future Research

The Suggestions for future research are aimed at continuing the present study in order to improve the proposed approach to quality assessment by extending it to types of passenger transport and analyzing it from different

perspectives. In this way, it is indicated as suggestions for future work:

- Evaluate the participation of the employees in effective positions and of the managers in the process of implantation of the quality system;
- Study the results obtained with the implementation of the proposed approach, evaluating the feasibility of the changes that need to be made in the BRT System service.
- Identify the factors that influence the quality of services provided by the BRT using quantum regressions.
- Use structural equation modeling to verify relationships established between variables.

Finally, it is suggested to use an approach to assess the quality of the service provider's vision and to seek other fuzzy operators to aggregate the judgment of the users.

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Appendix 1

Questionnaire for Quality Assessment

Part 1: Information about you.

- a) Age
- b) Sex
- c) City where you live
- d) Neighborhood in which you live
- e) Occupation
- f) BRT line used
- g) How many times a week is the BRT line used?

Part 2: The following set of statements refers to YOUR PERCEPTION OF THE SERVICE PROVIDED BY THE BRT SYSTEM.

-
- V01. The trips were fulfilled in the schedules;
 - V02. The stopping points had line schedules;
 - V03. The buses were driven safely;
 - V04. The buses were new and comfortable;
 - V05. The buses made little noise;
 - V06. The buses had air-conditioning working properly;
 - V07. The stopping points were comfortable;
 - V08. There was a one-way charge for the integrated transport service;
 - V09. There was the facility to park near the stopping points;
-

- V10. There was free internet in the vehicles and stopping point;
- V11. There were shops and convenience services near the staging points;
- V12. There was availability of telephone information on schedules and itineraries of the lines;
- V13. Whenever I contacted the transportation company she answered my questions;
- V14. There was availability of information from the transport service over the internet;
- V15. There were campaigns to use the public transport service;
- V16. The speed of public transportation vehicles was safe;
- V17. The buses stopped only at the stopping points;
- V18. The buses had security equipment;
- V19. The sidewalks and bike paths were close to the stopping points;
- V20. There was the facility to access the integrated transportation service (bus and subway);
- V21. There were physical structures adapted for those with special needs to access the transportation service;
- V22. You had a friendly attitude from the employees;
- V23. The attitude of the staff showed their willingness to help me;
- V24. My needs were quickly answered by the staff

References

- Bertini, R.L.: You are the traffic jam: an examination of congestion measures. In: 85th Annual Meeting of the Transportation Research Board, Washington, DC (2005)
- Ploeg, F.V.D., Poelhekke, S.: Globalization and the Rise of Mega Cities in the Developing World. Cesifo Working Paper No 2208, Category Trade Policy (2008)
- Rufolo, M., Bianco, M.J.: The Impact of Congestion Pricing and Parking Taxes on Spatial Competition. School of Urban Studies and Planning Portland State University, Portland (1998)
- Dell'Olio, L., Ibeas, A., Cecín, P.: Modelling user perception of bus transit quality. *Transp. Policy* **17**(6), 388–397 (2010)
- Deng, T., Nelson, J.D.: Bus Rapid Transit implementation in Beijing: an evaluation of performance and impacts. *Res. Transp. Econ.* **39**(1), 108–113 (2013)
- Kumar, V.S., Kumar, V.R., Rao, M.K.: Preliminary assessment of bus rapid transit system for urban roads. *Int. J. Technol. Res. Eng.* **4**(3), 439–443 (2016)
- Cervero, R., Dai, D.: BRT TOD: leveraging transit oriented development with bus rapid transit investments. *Transp. Policy* **36**(11), 127–138 (2014)
- Weisbrod, G., Mulley, C., Hensher, D.: Recognising the complementary contributions of cost benefit analysis and economic impact analysis to an understanding of the worth of public transport investment: a case study of bus rapid transit in Sydney, Australia. *Res. Transp. Econ.* **59**(1), 450–461 (2016)
- Levinson, H., Zimmerman, S., Clinger, J., Rutherford, S., Smith, R.L., Cracknell, J., Soberman, E.R.: Bus Rapid Transit, Case Studies in Bus Rapid Transit. Transit Cooperative Research Program: Report 90. Transportation Research Board, Washington (2003)
- Wright, L., Hook, W.: Bus Rapid Transit Planning Guide. Institute for Transportation & Development Policy. http://www.itdp.org/index.php/microsite/brt_planning_guide/. Accessed 26 Jan 2017 (2007)
- BRTDATA.ORG: Global BRT data. <http://brtdata.org/?lang=pt>. Accessed 5 Feb 2017 (2017)
- Ettema, D., Gärling, T., Eriksson, L., Friman, M., Olsson, L.E., Fujii, S.: Satisfaction with travel and subjective well-being: development and test of a measurement tool. *Transp. Res. Part F* **14**, 167–175 (2011)
- Eboli, L., Mazzulla, G.: Structural equation modelling for analysing passengers' perceptions about railway services. *Proc. Soc. Behav. Sci.* **54**(4), 96–106 (2012)
- Eboli, L., Mazzulla, G.: Service quality attributes affecting customer satisfaction for bus transit. *J. Public Transp.* **10**(3), 21–34 (2007)
- Chou, P.F., Lu, C.S., Chang, Y.H.: Effects of service quality and customer satisfaction on customer loyalty in high-speed rail services in Taiwan. *Transp. A Transport Sci.* **10**(10), 917–945 (2014)
- Stradling, S., Carreno, M., Rye, T., Noble, A.: Passenger perceptions and the ideal urban bus journey experience. *Transp. Policy* **14**(4), 283–292 (2007)
- Şimşekoğlu, Ö., Nordfjærn, T., Rundmo, T.: The role of attitudes, transport priorities, and car use habit for travel mode use and intentions to use public transportation in an urban Norwegian public. *Transp. Policy* **42**(8), 113–120 (2015)
- Yaya, L.H.P., Fortià, M.F., Canals, C.S., Marimon, F.: Service quality assessment of public transport and the implication role of demographic characteristics. *Public Transport* **7**(3), 1–20 (2014)
- Morton, C., Caulfield, B., Anable, J.: Customer perceptions of quality of service in public transport: evidence for bus transit in Scotland. *Case Stud. Transport Policy* **4**(3), 199–207 (2016)
- Parasuraman, A., Zeithaml, V.A., Berry, L.L.: A conceptual model of services quality and its implication for future research. *J. Market.* **49**(4), 41–50 (1985)
- Liou, T.S., Chen, C.W.: Subjective appraisal of service quality using fuzzy linguistic assessment. *Int. J. Quality Reliab. Manag.* **23**, 928–943 (2006)
- Batista, D.A., Medeiros, D.D.: Assessment of quality services through linguistic variables. *Benchmarking Int. J.* **21**(1), 28–45 (2014)
- Gouvello: Brazil Low-carbon Country Case Study. http://siteresources.worldbank.org/BRAZILEXTN/Resources/Brazil_Low_carbonStudy.pdf. Accessed 5 Feb 2017 (2010)
- Brazil: BRT Manual - Planning Guide. <http://www.cidades.gov.br/images/stories/ArquivosSEMOb/Biblioteca/ManualBRT.pdf>. Accessed 15 May 2017 (2008)
- Prates, M.: Five Cities Where Buses Work. <http://exame.abril.com.br/brasil/5-cidades-pioneiras-no-uso-eficiente-do-onibus/>. Accessed 26 Jan 2017 (2016)
- Grande Recife Consórcio de Transporte: BRT Via Livre. <http://www.granderecife.pe.gov.br/web/grande-recife/brt-via-livre>. Accessed 23 Jan 2017 (2015)
- Ferraz, N.A., Melo, F.J.C., Jerônimo, T.B., Albuquerque, A.P.G., Medeiros, D.D.: Evaluation of quality in services: real case in the hotel fitness center. *Braz. J. Tour. Res.* **12**(1), 1–27 (2018)
- Santos, R.R., Melo, F.J.C., Claudino, C.N.Q., Medeiros, D.D.: Model for formulating competitive strategy: the supplementary health sector case. *Benchmarking Int. J.* **24**(1), 219–243 (2017)
- Eboli, L., Mazzulla, G.: A methodology for evaluating transit service quality based on subjective and objective measures from the passenger's point of view. *Transp. Policy* **18**(1), 172–181 (2011)
- Cronin, J.J., Taylor, S.: Measuring service quality: a reexamination and extension. *J. Market.* **56**(3), 55–68 (1992)
- Bolton, R.N., Drew, J.H.: A multistage modelo f customers assessment of service quality and value. *J. Consum. Res.* **17**(4), 375–384 (1991)

32. Oña, J., Oña, R.: Quality of service in public transport based on customer satisfaction surveys: a review and assessment of methodological approaches. *Transp. Sci.* **1**(1), 1–18 (2014)
33. Oña, J., Oña, R., López, G.: Transit service quality analysis using cluster analysis and decision trees: a step forward to personalized marketing in public transportation. *Transportation* **43**(5), 725–747 (2015)
34. Findlay, P., Kalleberg, A.L., Warhurst, C.: Job types and job quality. *Eur. Hum. Relat.* **66**(4), 475–502 (2013)
35. Freitas, L.P.: Assessing the quality of intercity Road transportation of passengers: an exploratory study in Brazil. *Transp. Res. Part A Policy Pract.* **49**(3), 379–392 (2013)
36. Bian, J.W., Ding, M.: The effectiveness of the construction of the bus rapid transit in Xiamen City. In: Mackett, R.L., May, A.D., Kii, M., Pan, H. (eds.) *Sustainable Transport for Chinese Cities, Transport and Sustainability*, vol. 3, no. 1, pp. 255–275. Emerald Group Publishing, Portland (2012)
37. Silva, C.F.D., Batista, D.A., Medeiros, D.D.: A proposed method to evaluate the quality of services using fuzzy sets theory. *Qual. Quant.* **48**(2), 871–885 (2014)
38. Zadeh, L.A.: Knowledge representation in fuzzy logic. In: Yager, R.R., Zadeh, L.A. (eds.) *An Introduction to Fuzzy Logic Applications in Intelligent Systems*, pp. 2–25. Kluwer Academic Publisher, Boston (1991)
39. Yu, M.C., Keng, I., Chen, H.X.: Measuring service quality via a fuzzy analytical approach. *Int. J. Fuzzy Syst.* **17**(2), 292–302 (2015)
40. Hsu, W.: A fuzzy multiple-criteria decision-making system for analyzing gaps of service quality. *Int. J. Fuzzy Syst.* **17**(2), 256–267 (2015)
41. Tooranloo, H.S., Ayatollah, A.S.: Pathology the internet banking service quality using failure mode and effect analysis in interval-valued intuitionistic fuzzy environment. *Int. J. Fuzzy Syst.* **19**(1), 109–123 (2017)
42. Mishra, A.R., Jain, D., Hooda, D.S.: Exponential intuitionistic fuzzy information measure with assessment of service quality. *Int. J. Fuzzy Syst.* **19**(3), 788–798 (2017)
43. Xu, H., Fan, Z.P., Liu, Y., Peng, W.L., Yu, Y.Y.: A method for evaluating service quality with hesitant fuzzy linguistic information. *Int. J. Fuzzy Syst.* **20**(5), 1523–1538 (2018)
44. Hwang, C.L., Yoon, K.: *Multiple Attribute Decision Making: Methods and Application*. Springer, New York (1981)
45. Wang, Y.J., Lee, H.S.: Generalizing TOPSIS for fuzzy multiple-criteria group decision-making. *Comput. Math. Appl.* **53**(11), 1762–1772 (2007)
46. Celik, E., Bilisik, O.N., Erdogan, M., Gumus, A.T., Baraclı, H.: An integrated novel interval type-2 fuzzy MCDM method to improve customer satisfaction in public transportation for Istanbul. *Transp. Res. Part E* **58**(11), 28–51 (2013)
47. Massami, E.P., Myamba, B.M., Edward, L.: Fuzzy analysis and evaluation of public transport service quality: a case study of dar es Salaam City, Tanzania. *J. Transp. Technol.* **6**(6), 297–311 (2016)
48. Chen, C.T.: Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy Sets Syst.* **114**(1), 1–9 (2000)
49. Forza, C.: Survey research in operations management: a process-based perspective. *Int. J. Oper. Prod. Manag.* **22**(2), 152–194 (2002)
50. Faleiros, F., K appler, C., Pontes, F.A.R., Silva, S.S.C., Goes, F.S.N., Cucick, C.D.: Use of virtual questionnaire and dissemination as a data collection strategy in scientific studies. *Texto Contexto Enferm.* **25**(4), 1–6 (2016)
51. Hair, J.F.J., Black, W.C., Babin, B.J., Anderson, R.E., Tatham, R.L.: *Multivariate Data Analysis*. Prentice-Hall, Upper Saddle (2006)
52. Likert, R.A.: Technique for measurement of attitudes. *Arch. Psychol.* **140**(1), 5–55 (1932)
53. Mahmoud, M., Hine, J.: Using AHP to measure the perception gap between current and potential users of bus services. *Transp. Plan. Technol.* **36**(1), 4–23 (2013)
54. Oña, J., Oña, R., Calvo, F.J.: A classification tree approach to identify key factors os transit service quality. *Expert Syst. Appl.* **39**(12), 11164–11171 (2012)
55. Oña, J., Oña, R., Eboli, L., Mazzulla, G.: Perceived service quality in bus transit service: a structural equation approach. *Transp. Policy* **29**(9), 219–226 (2013)
56. Antunes, E.M., Simões, F.A.: Use of psychometrics to evaluate the quality of transport service: a case study. *J. Gestão Ind.* **09**(2), 416–439 (2013)
57. Nosal, K., Solecka, K.: Application of AHP method for multi-criteria evaluation of variants of the integration of urban public transport. *Transp. Res. Proc.* **3**(1), 269–278 (2014)

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