Assessment of Induced Fuzziness in Passenger's Perspective of Transit Service Quality: A Sustainable Approach for Indian Transit Scenario

Suprava Jena, Hetsav Dholawala, Mahabir Panda and P. K. Bhuyan

Abstract Passengers form the most important stake-holding body in public transit services. This study deals with the complexity of assessing transit service quality by identifying attributes affecting passenger's satisfaction. An innovative questionnaire was designed by taking passengers' demographic information and a wide spectrum of attributes related to operating conditions of two bus rapid transit systems (BRTS), i.e., Janmarg (Ahmedabad city) and Sitilink (Surat city) in the state of Gujarat. Total 23 variables are extracted using factor analysis with a Kaiser-Meyer-Olkin (KMO) value of 0.63 to conclude that the sample size is adequate enough for the model. These variables are grouped into six principal components and changed over to fuzzy sets with three membership functions each to map the fuzziness and ambiguity in passengers' perception. The complications of generating $3^6 = 729$ number of fuzzy rules are solved by introducing a hierarchical fuzzy inference system (FIS) with two lower-level FIS and one higher-level FIS. The first lower FIS consists of "accessibility," "service provisions," and "reliability" as fuzzy input variables to get "availability" as an output variable. The second lower FIS contains "safety and security," "fare," and "comfort" as input parameters to produce "comfort and convenience" as an output variable. The resulting fuzzy values are used in higher-level FIS and defuzzified to evaluate the satisfaction level of passengers by max-min composition technique. This method will help in improving existing transit facilities and devising strategies for ensuring sustainability.

Keywords Transit service quality · Perception survey · Factor analysis · Fuzzy inference system · Membership functions

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1   Introduction

At present, managing the road networks has been dreadfully challenging as demand increases and resources are limited. This often results in unruly traffic growth and congestion in the flow of traffic. If a city is properly planned and organized, public transits can fulfil up to 90% of the mobility requirements generated by private automobiles. This modal shift toward public transit can effectively reduce the use of private vehicles and lead to decongestion of streets, high mobility, time-saving, and better quality of life. However, public transportation systems in India are plagued by congested and overcrowded roadways operating under a chaotic environment. So, there is a bare need for improving the serviceability of public transportation system to reassure the travelers for modal shift, which can exemplify a step toward improving the environment. Many researchers have estimated the service quality offered by public transit system from varying perspectives. However, passengers form the most important stake-holding body in public transit services, and therefore, the complexity of transit service quality should be assessed from its user's perspective. Transit service quality is associated with a wide spectrum of attributes such as spatial coverage, service period, frequency, stop/station access, fare, speed, reliability, on-board comfort, safety, and security. Ensuring sustainability of transit service forms an important aspect, which directly depends upon upholding the existing users and attracting new users. Along with that, the choice of strategies should be made carefully to attain cost-effective implementations. The proposed research focusses on two aspects, such as (i) identifying influential attributes affecting passenger's satisfaction for existing transit services in developing countries and (ii) developing a suitable method for the evaluation of transit service quality, which will help in improving existing facilities and devising strategies for ensuring sustainability.

Some research work has been carried out for the determination of Transit service quality, taking passengers' perceptions of service quality. Morfoulaki et al. [1] studied the relationship between the service quality and the probability of customer being satisfied. Fu and Xin [2] proposed a new service quality index called transit service index (TSI), taking spatial and temporal variations in travel demand of a transit system. Dowling et al. [3] developed a new methodology for transit level of service (LOS) considering the transit to be internally dependent upon other modes of travel and pedestrian LOS. Tyrinopoulos and Antoniou [4] authors demonstrated a well-coordinated transportation environment to be the primary aim of the policy-makers in Athens, followed by other quality attributes. Eboli and Mazzulla evaluated the transit passenger's point of view using choice-based conjoint analysis. This study found frequency, reliability, cleanliness, and bus stop facilities are the influencing attributes affecting passengers' perception [5]. Dell'olio et al. [6] distinguished the perceived quality and the desired quality in public transportation taking different categories of users and potential users. Awasthi et al. [7] developed a hybrid model using SERVQUAL and Fuzzy TOPSIS for evaluating the service quality of urban transportation systems. Khurshid et al. [8] studied the impact of the transit service quality on male and female customers. The study revealed, males are more driving

conscious and females are highly dissatisfied with the waiting time, cleanliness, security, and seating issues. Mahmood and Hine [9] suggested that the individual analysis of both subjective (perception) and objective (performance) quality presents evidence for transit service quality evaluation. Noor et al. [10] identified that overcrowding and safety during night were among the most significant attributes affecting passengers' satisfaction. Pavlína [11] studied the service quality concept with the aim of quantifying factors and identified loyalty as the most important factors influencing passengers' satisfaction in Czech Republic. In this study, the variety of existing approaches has been justified by integrating the complexity of the service quality concept; the imprecision and subjectivity of the attributes used to analyze it; and the heterogeneity of passenger's perception.

2 Study Methodology

Considering different modeling approaches in the past few decades, a variety of deterministic and stochastic models have been employed to assess the service quality of transportation systems. But those customary techniques might not be effective when the inter-dependencies between variables are too complex. In reality, quantitative assessment of passenger's satisfaction is very intricate and difficult to decode as most of their decisions come off with fuzziness, ambiguity, and imprecision. Hence, an attempt was made in this study to assess the transit service quality using fuzzy logic by mapping the ambiguity of traveler's insight. Yet, the motive behind not taking all the responses composed as input parameters for the decision model as there may be a high correlation between each individual statement. Therefore, the data collected from the questionnaire were framed into uncorrelated set of variables using factor analysis.

2.1 Factor Analysis

Factor analysis is used to compress a large data set to smaller subsets of elements. This exploration is used for (i) understanding the arrangements of variables; (ii) building a questionnaire which processes the underlying variable; and (iii) reducing the data set to a more adaptable size to retain more novel information as possible. The factor analysis undertakes that the rankings of the variables are created by some unnoticed and underlying approaches. The basic formula of the factor analysis is explained by Eq. (1) as follows:

$$X_{ji} = \sum_{k=1}^{m} \left(\lambda_{jk} F_{ki} \right) + \varepsilon_{ji}, \tag{1}$$

where $j = 1.2,…, J$; $i = 1.2,…, N$; X_{ji} symbolizes the score of statement j for participant i; J signifies the number of statements; N signifies the number of observations; F_{ki} implies the kth factor of participant i; λ_{jk} (also known as loading) indicates the relation of jth variable with kth common factor; and ε_{ji} signifies the associated error. Equation (1) undertakes J statements, N observations and m factors considered in the model. It is required to be summon up that factor scores (F_{ki}) were not observed. This exploration calculates both factor scores and respective loadings to make best use of the information maintained from original statements.

KMO and Bartlett's test of sphericity is the main aspect in factor analysis. The KMO statistic is used to quantity sampling adequacy for each variable. KMO values greater than 0.8 is measured as good, i.e., the factor analysis is suitable for the variables. Bartlett's test of sphericity is related to the implication of the study to show the validity and correctness of the collected responses to address the problem. The value of Bartlett's test of sphericity <0.05 is recommended as a suitable value in factor analysis. Another important aspect mentioned in this study is rotated component matrix to decide the total number of factors that should be analyzed, if a variable is linked to more than one factor. Rotation maximizes high item loadings and minimizes low item loadings to produce a simplified solution. In this study. orthogonal varimax rotation technique is used that produces uncorrelated factor structure. To measure the consistency of a questionnaire, reliability analysis (denoted by Cronbach's alpha) is used.

2.2 Fuzzy Inference System

The human brain interprets imprecise and incomplete sensory information provided by perceptive organs. Fuzzy sets theory provides a systematic calculus to deal with such information linguistically, and it performs numerical computation by using linguistic labels stipulated by membership functions (MF). Moreover, a selection of fuzzy if-then rules forms the key component of a fuzzy inference system (FIS) that can effectively model human expertise in a specific application. Although the fuzzy inference system has a structured knowledge representation in the forms of fuzzy if-then rules, it lacks the adaptability to deal with changing external environments.

Fuzzy Set Theory
In contrast to a classical set, a fuzzy set, as the name implies, is a set without a crisp boundary. That is, the transition from "belong to a set" to "not belong to a set" is gradual, and this smooth transition is characterized by membership functions that give fuzzy sets flexibility in modeling commonly used linguistic expressions. Such imprecisely defined sets or classes play an important role in human thinking, particularly in the domains of pattern recognition, communication of information, and abstraction. As fuzzy sets have smooth boundaries of transition, a belongingness of a particular value to the fuzzy set is represented by a membership function. A

fuzzy set can be explained mathematically; If X is a collection of objects denoted generically by x, then a fuzzy set A in X is defined as a set of ordered pairs:

$$A = [\{x, \mu A(x)|x \in X\}] \tag{2}$$

where $\mu A(x)$ is called the membership function for the fuzzy set A. The MF maps each element of X to a membership grade between 0 and 1.

Fuzzy Reasoning

Fuzzy reasoning, also known as approximate reasoning, is an inference procedure that derives conclusions from a set of fuzzy if-then rules and known facts. The basic rule of inference in traditional two-valued logic is modus ponens, according to which we can infer the truth of a proposition B from the truth of A and the implication $A \rightarrow B$. Premise 1 (fact): x is A, Premise 2 (rule): if x is A then y is B, Consequence (conclusion): y is B. Where A' is close to A and B' is close to B. When A, B, A', B' are fuzzy sets of approximate universes, the foregoing inference procedure is called approximate reasoning or fuzzy reasoning. The fuzzy membership functions for linguistic variables along with these fuzzy if-then rules compose a framework of fuzzy knowledge base of fuzzy expert system. Imposing any values of the variables, knowledge bases can infer a consequence using expert system.

Defuzzification

The fuzzy inference system can take either fuzzy inputs or crisp inputs, but the outputs it produces are almost always fuzzy sets. Sometimes, it is necessary to have a crisp output. Therefore, defuzzification of the fuzzy sets has to be done so as to achieve a crisp output. With crisp inputs and outputs, a fuzzy inference system implements a nonlinear mapping from input to output space. This mapping is accomplished by a number of fuzzy if-then rules, each of which describes the local behavior of the mapping. In particular, the antecedent of a rule defines a fuzzy region in the input space, while the consequent specifies the output in the fuzzy region.

3 Study Area

To achieve the objective of the proposed research, a perception survey was conducted in two urban agglomerations, i.e., Janmarg (Ahmedabad city) and Sitilink (Surat city) in the state of Gujarat, India, to gather required information on passenger's satisfaction about bus rapid transit systems (BRTS). Figure 1 shows BRTS routes of the two studied cities. The selection of the study area is done on such basis that simulates the urban agglomerations and prevalent conditions, i.e., traffic characteristics of the area to the maximum extent. So that the entire spectrum of operating conditions can be modeled. As in this research, the passengers' satisfaction is considered for assessing the quality of service of public transit which operates on prescribed routes
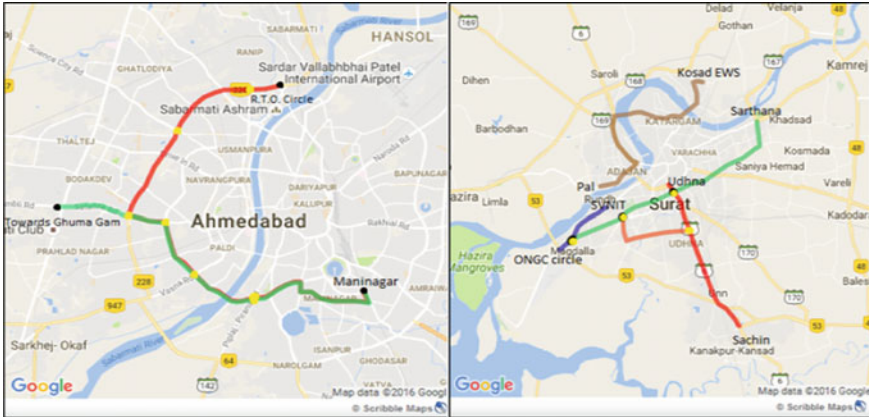
Fig. 1 Map showing study area in Janmarg BRTS and Sitilink BRTS, respectively

and on fixed schedule, e.g., in Janmarg BRT, the routes from Maninagar to Ghuma Gam and from Maninagar to Chandkheda were found to be in utmost demand. Apart from being the most important routes in the network, these routes incorporate most number of transfer points. Hence, it can be assumed that on these transfer points, passengers from the farthest ends of the networks are present.

4 Data Collection

An innovative questionnaire was designed by taking sets of operating conditions of BRTS at bus stops, routes, and at network levels as shown in Table 1. The whole questionnaire was divided into two subsections. The first section was about the respondents' personal profile, e.g., age, gender, purpose of travel, trip origin-destination, etc. The second part consists of 19 quality of service attributes those might have significant influence on passenger's satisfaction level, e.g., mode of access, ease of access, cleanliness, fare structure, service coverage, etc. The survey forms were distributed among the participants at important pick-up bus stops and inside the buses. The participants were asked to rate each service attribute and the overall satisfaction (OS) on a Likert scale ranging from "1" (highly dissatisfied) to "5" (highly satisfied). For better understanding of participants, the technical terminologies were explained in regional languages. Nearly 320 participants were interviewed while waiting at bus stops or traveling by bus. The diversity in demographic and socio-economic variables during data collection from different locations showed a strong potential of data sets to model transit service quality.

Table 1 Synopsis of variables and the measuring units

Variables	Units of measurement			
Gender	Male		Female	
Age	15–25	26–40	41–55	>55
Trip purpose	Work	Business	Education	Recreation
	Likert scales (1–5)			
Accessibility	Walking	Bicycle	Auto	Any Other
Transit frequency	5–10 min	10–30 min	30–60 min	>1 h
Parking provision	Present		Absent	
Transit availability, ease in access, bus stop nearness, in bus time, transfers, fare structure, fare collection, reliability, seating/standing, boarding/alighting, door width, cleanliness, lighting conditions, personnel behavior, comfort, accidents/breakdowns, and safety and security	Likert scales (1–5)			
Overall satisfaction	Likert scales (1–5)			

5 Result and Discussion

This section provides a detailed discussion about factor analysis to decide the input variables and application of fuzzy logic for the model development process. The prediction performance of the input parameters was also assessed in terms of several statistical parameters.

5.1 *Factor Analysis*

Factor analysis was carried out on the 23 statements with varimax rotation (orthogonal). The analysis starts by testing the validity of the data analysis with the help of Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity.

The test is proposed to find out whether all the examined data are adequate to be factored analysis. Factor is suitable if KMO value is greater than 0.60. With the KMO value 0.631 for the collected data, it shows that the data do not have a multi-collinearity problem and the suitable items are appropriate to test its factor analysis. Bartlett's test of sphericity is used to recognize that the correlation among the items is adequate for factor analysis.

The factor analysis is implemented using principal component analysis and varimax rotation with the objective to test the underlying factor structure of the data. Total five items with a factor loading smaller than 0.50 were discarded and items that cross-loaded too. Table 2 contains the rotated factor loadings, which signify both weighted variables and the correlation between the variables and the factor. Firstly, to reduce the multi-collinearity among the input variables, factor analysis was conducted over the collected responses. Total 18 variables were found to be significant,

Table 2 Rotated component matrix

Component	1	2	3	4	5	6	7
Gender	−0.045	−0.620	0.162	0.137	0.103	0.318	−0.232
Trip purpose	−0.062	−0.173	−0.065	0.339	−0.028	0.669	−0.061
Age	−0.129	−0.074	−0.048	0.031	−0.063	−0.685	−0.038
Temporal availability	−0.033	0.622	−0.041	0.106	−0.169	−0.096	−0.221
Spatial availability	0.419	−0.193	0.068	−0.019	0.569	−0.031	−0.230
Ease in access	−0.876	−0.073	0.144	0.023	−0.007	−0.091	−0.001
Mode of access	0.689	−0.179	−0.088	0.035	0.005	0.093	0.123
Parking	−0.015	0.620	0.251	−0.259	0.107	0.155	−0.188
Bus stop nearness	0.897	0.000	−0.108	−0.045	−0.081	−0.037	0.006
In bus time	−0.283	−0.101	0.694	−0.049	0.187	−0.071	0.170
Transfers	−0.097	−0.111	0.479	0.106	−0.051	−0.489	−0.055
Fare structure	−0.027	−0.121	−0.085	0.003	0.570	0.390	0.208
Fare collection	0.010	0.082	0.147	0.297	0.470	−0.012	0.405
Reliability	−0.116	0.407	0.617	−0.038	−0.152	0.110	−0.234
Seating/standing	0.021	−0.107	0.541	0.402	−0.034	−0.106	0.078
Boarding/alighting	−0.011	−0.130	−0.022	0.092	−0.021	0.073	0.769
Door width	0.337	−0.051	0.270	0.203	−0.027	−0.112	0.508
Cleanliness	−0.047	0.132	0.179	0.641	−0.207	0.273	0.076
Lighting conditions	−0.149	0.617	−0.192	0.219	−0.107	0.168	0.024
Personnel behavior	−0.055	−0.070	0.036	0.676	0.282	−0.046	0.057
Comfort	−0.121	−0.279	0.512	−0.045	0.277	0.242	0.352
Accidents/breakdowns	−0.153	−0.098	0.054	0.097	0.615	−0.026	−0.069
Safety and security	0.159	0.068	−0.156	0.517	0.339	0.077	0.252

which were précised into six uncorrelated set of variables such as accessibility, service provisions, reliability, safety and security, fare, and comfort.

5.2 Hierarchical Fuzzy Inference System

The six input variables were changed over to fuzzy sets with "bell" shaped membership function due to simpler formula and computational efficiency. Total six primary input variables taken into consideration for the prediction model and each variable has three descriptors. So, there might be complications in generating $3^6 = 729$ number of fuzzy rules. This rule explosion problem can be solved by introducing a hierarchical fuzzy inference system (FIS), which is subdivided into two lower-level FIS and one higher-level FIS. The two higher-level fuzzy components are (i) availability (AVAL) and (ii) comfort and convenience (CC). These two parameters are further taken as

input variables for mapping them into overall satisfaction observed by transit user. The model is suggested keeping in mind that the customer satisfaction is mapped on the stop levels and route/segment levels and not for entire network. The first lower FIS consists of "accessibility," "service provisions," and "reliability" as input variables, which were fuzzified to get "availability" as an output variable. Similarly, "safety and security," "fare," and "comfort" were the input parameters for second lower FIS to produce "Comfort and Convenience" as an output variable. The resulting fuzzy values are the input variables for higher-level FIS to evaluate the satisfaction level of passengers. Centroid and max-min composition techniques were used to defuzzify the continuous membership functions for the determination of transit LOS of both the cities.

Construction of Membership Functions
Membership functions are the most important aspect of fuzzy inference system. "Fuzzification from crisp data set to fuzzified data set" and "defuzzification from fuzzified data set to crisp data set" are based entirely upon the parameters of membership function. Fuzzy membership functions include two details to be quantified, i.e., shape of MF and parameters of MF. Each variable is categorized as per human perception and given the linguistic labels such as "Poor," "Fair," and "Good" in an ascending order. The shape of MF used here is generalized bell function. Each parameter of "*bellmf*" controls a particular property of the function. The top width, the slope, and the midpoint are controlled by the parameters *a, b,* and *c,* respectively. In order to evaluate these parameters, histograms, i.e., graph between frequency and category was drawn and the shape of it proposed bell function to be used as a membership function. The parameters used to construct MF for each variable along with linguistic label are shown in Table 3.

Construction of Membership Functions
The constructed set of fuzzy if-then rules for linguistic variables are based on a framework of fuzzy knowledge base of fuzzy expert system. For example, Premise 1 (fact): If availability is poor and comfort and convenience is poor, Consequence (conclusion): Then overall satisfaction is "*F.*" Similarly, all other fuzzy rules are generated by every possible combination of MFs.

Defuzzification
The outputs from fuzzy logic can be of two types: (a) fuzzy set and (b) crisp output. It is often required to have a crisp value at the end of fuzzy analysis. As for our analysis, the aim is to achieve the overall satisfaction of the respondents, we need a crisp output. Therefore, a fuzzy linguistic label that has resulted from the FIS has be defuzzified and converted back to crisp value output. This process is termed as defuzzification. The defuzzification technique used here is "Centroid technique." Center of gravity also known as centroid method is the commonly used defuzzification strategy for continuous membership functions. Table 4 shows an example of how to obtain LOS category out of the fuzzy analysis. The score corresponding to "AVAL" and "CC" are the defuzzified fuzzy score from lower-level fuzzy logics. These scores are further

Table 3 Fuzzy membership functions parameters

	Variable	Category	MF grades (*bellmf*)		
			a	b	c
First lower-level FIS	Accessibility	Poor	0.8	3.366	1.201
		Fair	0.57	2.5	2.75
		Good	1.02	3.84	4.555
	Service provision	Poor	2.27	7.32	0.2567
		Fair	0.728	2.5	3.41
		Good	1.27	5.55	5.57
	Reliability	Poor	2.27	7.32	0.2567
		fair	0.728	2.5	3.41
		Good	1.27	5.55	5.57
Second lower-level FIS	Safety and security	Poor	2.27	7.32	0.482
		Fair	0.676	2.5	3.69
		Good	1.27	5.55	5.835
	Fare	Poor	2.27	7.32	0.1509
		Fair	0.818	2.5	3.35
		Good	1.21	4.93	5.441
	Comfort	Poor	2.41	9.45	0.0979
		fair	0.852	4.332	3.36
		Good	1.21	4.618	5.43
Higher-level FIS	Availability	Poor	1.5	6.328	1.12
		Fair	0.8	4.095	3.42
		Good	0.9	3.818	5.13
	Comfort and convenience	Poor	0.9	4.21	1.54
		Fair	0.8	3.97	3.245
		Good	0.9	4.18	4.946

Table 4 Membership grades and defuzzification process

No.	Input		LOS	Max-Min composition
	AVAL	CC		
5	Fair (0.22)	Fair (0.99)	D	Min (0.22,0.99) = 0.22
6	Fair (0.22)	Good (0.008)	C	Min (0.008,0.22) = 0.008
8	Good (0.7519)	Fair (0.99)	B	Min (0.7519, 0.99) = 0.7519
9	Good (0.7519)	Good (0.008)	A	Min (0.008, 0.7519) = 0.008
Max of (D = 0.22; C = 0.008; B = 0.7519; A = 0.008) = B				

Table 5 Route-wise LOS counts in percentage for in each category

Segment	Route	LOS counts (%)						Total
		F	E	D	C	B	A	
1	Maninagar to Shivaranjani	0	11.5	69.2	19.2	0	0	100
2	Shivaranjani to Maninagar	0	12.5	62.5	12.5	12.5	0	100
3	Maninagar to RTO	0	8.11	83.8	8.11	0	0	100
4	RTO to Maninagar	0	0	71.4	28.6	0	0	100
5	Maninagar to Ghuma gam	0	0	92.3	7.69	0	0	100
6	Ghuma gam to Maninagar	0	0	66.7	33.3	0	0	100
7	Pal RTO to Kosad	0	16.7	66.7	16.7	0	0	100
8	Kosad to Pal RTO	0	0	100	0	0	0	100
9	Sarthana to Dumas	0	11.1	44.4	44.4	0	0	100
10	Dumas to Sarthana	0	0	80	20	0	0	100
11	Udhna to Sachin	0	0	90	10	0	0	100
12	Sachin to Udhna	0	0	100	0	0	0	100
13	SVNIT to Dumas	0	0	25	75	0	0	100
14	Dumas to SVNIT	0	0	0	100	0	0	100

used to predict the outcome, i.e., overall satisfaction of respondent. The scores were further classified as per the membership grades (α cuts). These membership grades were used to obtain OS values using centroid method. The significant rules were Rule# 5, 6, 8, and 9. Max-min composition resulted into LOS category of *B*. The observed value from the respondent was 4 which largely falls into "*B*" LOS levels. The collected data were classified route-wise as well as direction-wise due to the fact that BRTS have exclusive routes for its bus service as well different segments are provided direction-wise. Hence, the possibility of a single LOS level being dominant over all routes is rather less. The range in which LOS falls majorly as well as the aggregate behavior of respondents is important from the managerial perspective. Table 5 shows 14 entries for seven different routes direction-wise. The total responses were cross-classified between different categories of LOS and different route segments.

6 Conclusion

The proposed research focusses on identifying influential transit service attributes affecting passenger's satisfaction and developing a suitable method for the evaluation of existing transit service quality to devise strategies for its sustainability. Considering

different modeling approaches in the past few decades, a variety of deterministic and stochastic models have been employed to assess the service quality of transportation systems. But those customary techniques might not be effective, when the inter-dependencies between variables are too complex. In reality, quantitative assessment of passenger's satisfaction is very intricate and difficult to decode as most of their decisions come off with fuzziness, ambiguity, and imprecision. Hence, fuzzy inference system is applied in this study to assess the transit service quality by mapping the ambiguity of passenger's perception in two bus rapid transit systems (BRTS), i.e., Janmarg (Ahmedabad city) and Sitilink (Surat city) in the state of Gujarat, India.

Factor analysis results in six input variables with a Kaiser-Meyer-Olkin (KMO) value of 0.63, which represents the sample size is adequate enough for the proposed model. The six input variables were changed over to fuzzy sets with "bell"-shaped membership function. Each variable has three descriptors. So, there might be complications in generating $3^6 = 729$ number of fuzzy rules. This rule explosion problem can be solved by introducing a hierarchical fuzzy inference system (FIS), which is subdivided into two lower-level FIS and one higher-level FIS. The resulting fuzzy values from lower-level FIS are the input variables for higher-level FIS to evaluate the satisfaction level of passengers on fourteen routes of the two BRTS "Janmarg" and "Sitilink." These kinds of models have not yet come into attention, which uses linguistic information and real-life problems of passengers about the current state of services. Hence, the proposed method would be more credible than previous models to support the decision-makers for long-term planning and designing transit networks.

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