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LEVEL OF PUBLIC TRANSPORT SERVICE EVALUATION: A FUZZY SET APPROACH

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The success of any enterprise, in a market-oriented economy, depends upon it's quality. This paper describes the results of a survey of commuters on the quality of services and their relative weights, and of the attributes that determine the service level of bus transport undertakings. The model uses the theory of fuzzy sets to process the information obtained. A composite index, called level-of-public transport-service (LOPTS), is defined and used to measure the service qualities. This approach is presented with guidelines for rating the quality of services, fuzzy-set representations of the linguistic grades, definition of LOPTS and its use in a public transport quality data base. An example is presents how the approach can be employed to analyse data bases generated from a quality survey. This approach is compared with the numerical rating approach with single number representation.

Introduction

The American Association of State Highway and Transportation officials (AASHTO) and its member departments are committed to continually improving the quality of their organisations and activities, a process often referred to as Total Quality Management (TQM) or continuous quality improvement. TQM is a management philosophy concerned with people and work processes that focuses on customer satisfaction and organisational performance. Many organizational efforts on quality begin with concerns about services and employees. However, in recent years, American businesses have been more successful when it took a broader approach and focussed on customer-based quality (CBQ). CBQ,

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an integral part of TQM, is becoming a hub of activity for state departments of transportation. CBQ also tune into customer wants and needs, developing ways to respond to them more effectively, and then assessing how well a state transport undertaking (STU) has performed and how satisfied customers are with a STU's services.

All efforts to improve the service development and employee performance could fail unless there is a clear understanding of the needs, desires and expectations of the customer. The STU which succeeds in building up a fairly good public image and which earns a niche in the hearts of the travelling public will only survive in the competitive environment, which arises in India due to liberalisation.

Importance of Quality of Service in Transport System

The aim of any good transport system should be to provide an adequate level-of-service (LOS) for all of its routes. However, the quality requirement of service varies with the expectation of the users. In the developed countries, where the demand for public transport is low, the service authorities try to attract passengers" attention by providing maximum possible LOS. Attributes like air conditioning, high levels of comfort, safety and reliability, etc. are being weighted highly by the users. However, the situation is completely different in a developing country, like, India. Here, the demand for transportation is very high in comparison to the supply. Since the personalized vehicle ownership is also low, a large percentage of the dwellers are captive users of transport, mainly the bus transport, except in a few metropolitan cities.

To evaluate the public transit system from the point of view of the LOS provided, Botzow (1974) developed a methodology for analyzing the trips in the Bay Area Rapid Transit System, Botzow (1974). Allen discussed the usefulness of measurement of LOS for management, governmental policy formulation and determination of subsidy levels, Allen (1976). Colin considered accessibility, travel time, reliability, directness of service, frequency and passenger density as the six LOS indicators which can motivate potential riders, Colin (1976). Bakker discussed the strategies of transit operation, differentiating between the all-day service function and the peak-hour operation, Bakker (1976). Dhingra analysed an intra-city travel survey conducted on three routes of South Delhi, considering nine important attributes, Dhingra (1986). Service levels of different categories of buses in two routes of Calcutta, is evaluated by Ray (1994). Literature review reveals mostly the use of the conventional scaling approach with single number representation for LOS determination. The focus of this paper is on the use of fuzzy sets, generally regarded as an effective tool to process the qualitative information, in the Level-of-Public-Transport-Service (LOPTS) index formation .

Mainly the objectives of this paper are as follows:

1. To identify the important service characteristics to determine the LOPTS provided by an STU.
2. To assess the weightages on the identified service characteristics from the regular users of state bus transport.
3. Evaluation of quality of services provided by city and district bus services of an STU in its operating zone.
4. To arrive at a composite index, called LOPTS through fuzzy set approach and numerical rating approach. This will indicate the position of a STU and will serve as the base for the improvement of overall service level of the system.
5. To compare the results of these approaches with each other for suitability.

Determination of Level of Bus Transport Service Through Numerical Rating Approach

Level-of-public transport-service (LOPTS) provided by a category of bus is defined as the composite index of various service qualities.

Mathematically $$LOPTS = \sum_{i=1}^{N} (R_i * W_i) / \sum W_i \qquad \text{..... (a)}$$

where;

N = No.of attributes that define the overall LOPTS

W_i = Weight associated with the i^{th} service attribute

R_i = Value score for the i^{th} service attribute for the category of bus service for the existing situation.

For a particular service attribute the LOPTS of a bus service is expressed as:

$$LOPTS_i = R_i \times W_i \qquad \text{...... (b)}$$

If the scale for weight associated with the service attributes is such that

$$\sum_{i=1}^{N} W_i = 1$$

and the value score is expressed with respect to unity, then the maximum possible LOPTS as per equation (a) is one.

LOPTS values closer to 1 indicate very high LOPTS, whereas, closer to 0 indicates very poor service level. However, practically no bus system is expected to provide a LOPTS as high as 1. Thus, it is important to know the accepted LOPTS, by the users, in a developing country like India. However, from the literature review, it is observed that 0.6 is used as the value for accepted service level (Debasish Ray, 1994; Dhingra, 1986; Murugesan, 1996) and the same value is considered in this study also.

Bus Transport Service Level Analysis Using Fuzzy Sets

In the proposed approach, the weightage and rating of a service quality according to a particular type of service attribute is assessed and recorded in terms of a linguistic or letter grade. The advantages of using linguistic grades for ratings and weights in a predominantly qualitative engineering evaluation are well documented (Elton 1988; Juang 1990; Murthy 1990; Zadeh 1983; Juang 1982). One of the effective methods for processing and combining the qualitative information obtained is to process the information with the following equation (Schmucker, 1984).

$$R = \sum_{i=1}^{N}(R_i * W_i)/\sum W_i \qquad \text{........(1)}$$

where, R = the overall rating of service level of a category of bus service ; R_i = the rating of the i^{th} service quality of the category of bus service for the existing condition; W_i = the weight of that service attribute i; and N = Number of attributes that define the overall service level. Each term in the right-hand side of (1) is a linguistic grade or, simply, a letter grade- A,B,C,D or E. A rational approach to evaluate eqn. (1) is to represent these letter grades with fuzzy sets, rather than using a single number to represent a letter grade, as is done in the conventional numerical rating approach (Zadeh, 1965). A fuzzy set is a set of paired numbers that describes the degree of support to each service quality. In describing the service quality, the attributes for which higher values represent higher level of satisfaction (e.g., comfort level of seats), have been represented as very high (highly satisfactory) = A, high = B, moderate = C, low = D and very low = E. The attributes for which lower values represent higher level of satisfaction (e.g., noise) have been represented as very low (highly satisfactory) = A, low = B, moderate = C, high = D, very high = E.

For example, in describing the noise level inside the bus, a letter grade of D means the service quality is in a poor state. On a conventional rating scale of say between 2-10, with 2 being the very high noise , a number-say 4- may be used to represent the grade D. While the rating grade 4 might be more appropriate, other numbers might also be appropriate. Thus, to represent the perception of high with a single number 4 seems to be too abstract. In the proposed approach, the letter grade D is represented by a fuzzy set defined as follows (for simplicity, a discrete fuzzy set is used here): (0/1, 0.67/3, 1.0/4, 0.5/5, 0/6). This fuzzy set may be interpreted in the following manner. The numerical grade 4 is most appropriate to represent the letter grade D (with a degree of support or confidence of 1.0). The numerical grades of 2, 3 or 5, however could also be used to represent this grade, although with a lesser degree of confidence (0.33, 0.67, 0.5). Other numerical grades are not as appropriate to represent this grade, as the confidence is none.

Thus, fuzzy sets can account for uncertainty associated with quantification of the linguistic or letter grade. In other words, these letter grades, when they are used along with the fuzzy sets in a qualitative evaluation, can form a comprehensive rating scale. The fuzzy sets that represent the letter grades adopted in this study are characterized by their membership functions as shown in Table 1 and in Fig.1. In this study a linear (triangular) membership function is assumed for simplicity in illustrating the presented methodology, (Juang, 1990; Juang, 1992; Dong, 1987).

When each term in the right-hand side of (1) is substituted by a fuzzy set, the evaluation of the equation involves operations such as fuzzy-set addition, fuzzy-set multiplication and fuzzy-set division. Definitions of these fuzzy operations, as one might expect, are different from their counterparts in the conventional mathematics (Schmucker, 1984). Rather than directly implementing these operations as it is tedious, the following

Table-1: Membership Functions of Fuzzy Sets that Represent Letter Grades for Ratings and Weights

Description for weight	Letter Grade (Fuzzy Set) (1)	Membership Function, f(y) (defined over a real interval, (0,1))	
Extremely important	A	f(y) = 5(y-0.8),	0.8 ≤ y ≤ 1.0
Very important	B	f(y) = 10(y-0.5)/3,	0.5 ≤ y ≤ 0.8
		f(y) = 5 (1.0-y),	0.8 ≤ y ≤ 1.0
Important	C	f(y) = 10(y-0.3)/3,	0.3 ≤ y ≤ 0.6
		f(y) = 5(0.8-y),	0.6 ≤ y ≤ 0.8
Moderately important	D	f(y) = 10(y-0.1)/3,	0.1 ≤ y ≤ 0.4
		f(y) = 5(0.6-y),	0.4 ≤ y ≤ 0.6
Less important	E	f(y) = 5(y),	0.0 ≤ y ≤ 0.2
		f(y) = 5(0.4-y),	0.2 ≤ y ≤ 0.4

process is used in this study, Dong (1987). The general concept for processing fuzzy information using a model such as (1) is illustrated in Fig.2. The main idea is to "defuzzify" each fuzzy set into a group of real intervals before entering into eqn. (1). Once this is accomplished, the conventional mathematics takes over, which results in a group of nonfuzzy intervals as the output. The final fuzzy set is reconstructed from this group of nonfuzzy intervals. A computer program Best Alternative Selection System (BASS) is also available to implement the computational process (Juang, 1988; 1991). The final result of the computation is a fuzzy set that represents the overall service level. An example showing the entire computation process is given in Appendix-1.

Level- of-Public-Transport-Service

For creating a quality management system using the results of the service quality observation of a bus service and fuzzy set analysis, a composite index called level-of-public-transport-service (LOPTS) is used. The LOPTS is defined as the composite index of various service characteristics provided by a category of bus of STU. It is based on the final fuzzy set that represents the bus service level, and takes the following form (ref. Fig.(3a)).

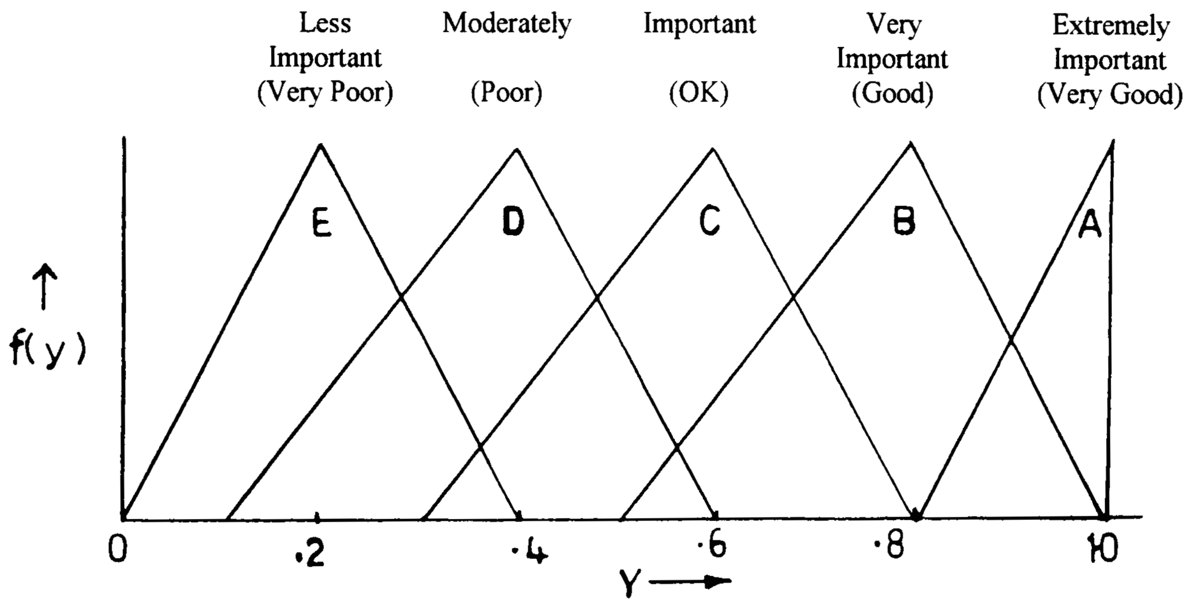

Figure 1. Membership Functions (Linear) of Fuzzy Sets that Represent Letter Grades for Ratings and Weights.

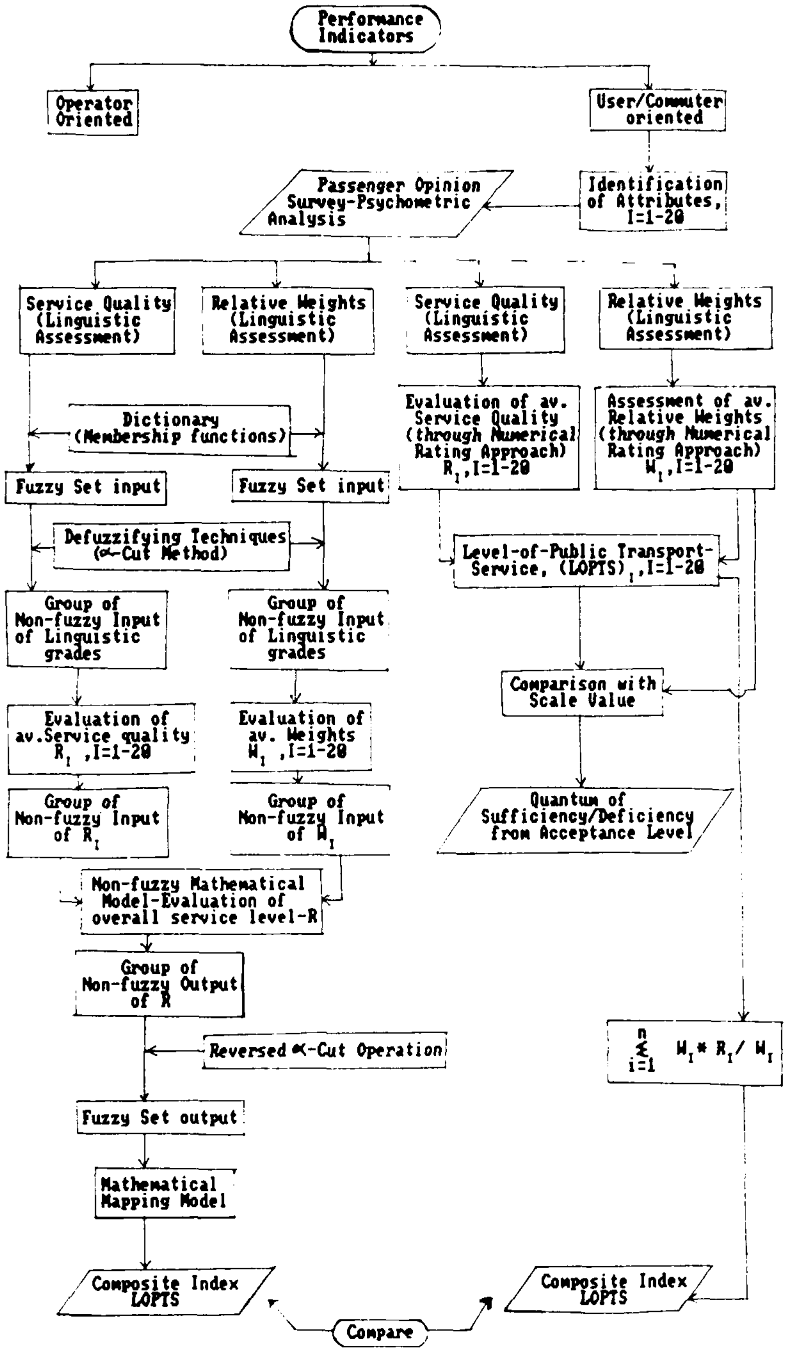

Figure 2. Methodology for Evaluating Level of Public Transport Service - A Fuzzy Set Approach.

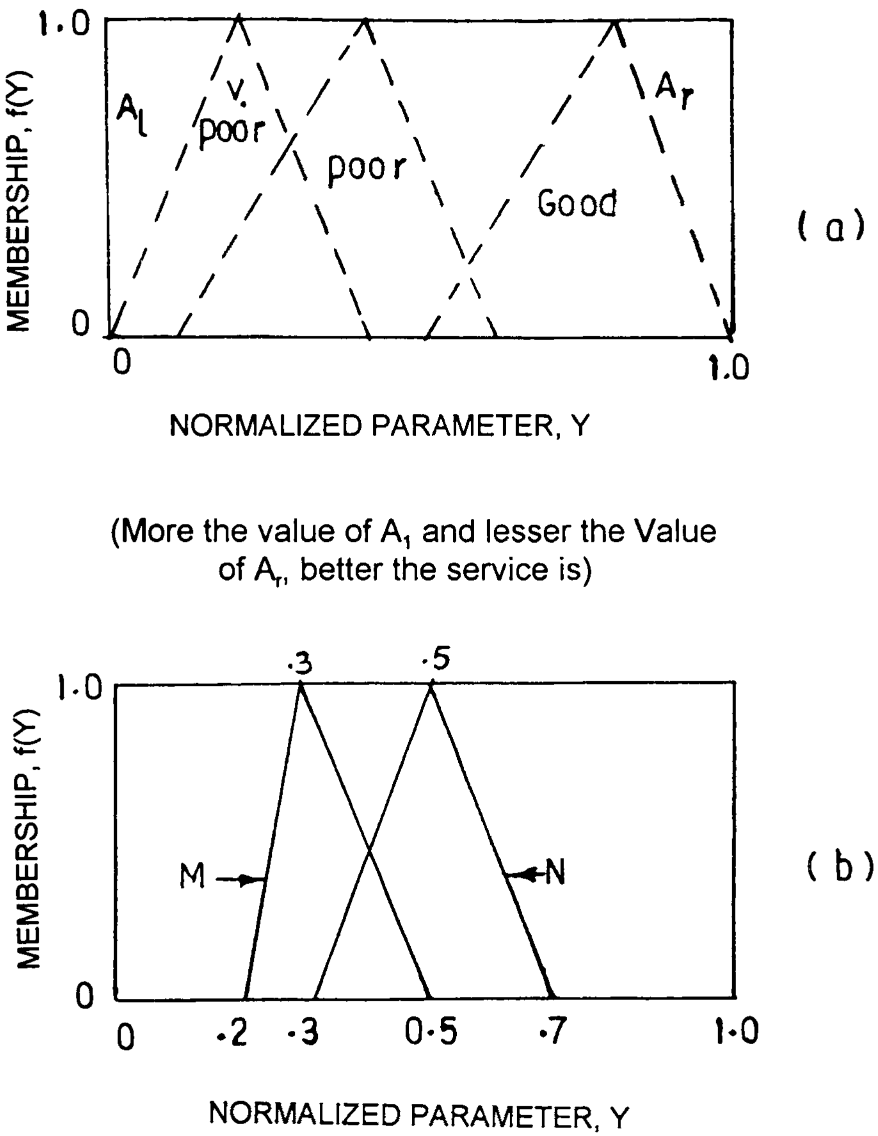

Figure 3. (a) Parameters of LOPTS and (b) Example of Fuzzy Sets for Calculating LOPTS

$$LOPTS = (A_l - A_r + 1)/2 \text{ ...... } (2)$$

where A_l = area enclosed to the left of the membership function that depicts the final fuzzy set, which varies with overall rating of service level, i.e. more the overall rating more the A_l value is; and A_r = area enclosed to the right of the membership function that depicts the final fuzzy set. The defined LOPTS value ranges from 0.0 to 1.0, with 1.0 indicating the perfect service level and 0.0 indicating the worst service level. The more the value of A_l and lesser the value of A_r, the better the service; the lesser the value of A_l and more the value of A_r, the poorer the service. For example, different services with overall ratings represented by fuzzy sets X and Y, given in Fig.3(b), are compared as follows:

For X : $A_l = (0.2 + 0.3)/2 = 0.25$; $A_r = (0.5 + 0.7)/2 = 0.60$
LOPTS = (0.25 - 0.6 + 1)/2 = 0.3125
For Y : $A_l = (0.3 + 0.5)/2 = 0.4$; $A_r = (0.3 + 0.5)/2 = 0.4$
LOPTS = (0.4 - 0.4 + 1)/2 = 0.50

The bus service represented by fuzzy set Y is in better level than the bus service represented by fuzzy set X.

A Case Study of Jeeva Transport Corporation

To facilitate the use of the proposed approach an attempt is made to assess the LOPTS provided by Jeeva Transport Corporation (JTC) Ltd., a STU in Tamilnadu State, India. This STU offers two categories of services, one is the city service, and the other is district service. City service radiates from the depots centres to the rural areas, stopping at all the stops enroute. District service is operated between the important towns in the district concerned and covers the nearby towns of surrounding districts, stopping only at smaller towns enroute.

Data Collection and Analysis

Twenty attributes have been judiciously chosen to determine the LOPTS provided by the city and district services separately. These include walking distance to the bus stop (access at origin), waiting time at the bus stop, condition and availability of bus shelters, frequency of bus service, regular arrival of buses without cancellation of trips, arrival, departure timings as per schedule (punctuality), ease of exit and entry from and into the bus with respect to door size and step height, ease of passenger movement inside the bus, space/seat availability in the case of city and district buses respectively, comfort level of seats regarding width etc., maintenance condition and cleanliness of bus, behaviour (inter-personnel movements) of conductors and drivers with passengers, fare level charged, journey speed of the bus, noise level inside the bus due to its fittings and type of engine, jerk experienced by the passengers, safety for passengers and goods, route information written on the sides of the bus and announcement of place names at the stops, ease of getting the next bus at the transfer points (if any) and the walking distance from the bus stop, at destination.

The survey is conducted under the supervision of the authors, by the qualified enumerators through interview with passengers. Their opinions are noted down in the printed questionnaires for assessing relative weights and rating the existing service qualities, for all the attributes. The survey is conducted for the city and district services separately at the bus stands of the 14 towns, where the 19 JTC depots are located. Fleet strength in the depots ranges between 31-63, except in the one located in the ghat region for the fleet strength of 13. From the passengers waiting for the buses, one thousand are surveyed during the month of January, 96, from 9.00 A.M. to 6.00 P.M. The quantum of sample for each depot location varies from 45-65, except for the one specified, depending upon the number of city and district buses in the respective depots. Respondents are chosen at random and care is taken to have responses from various socio-economic backgrounds.

A group of passengers, who use the JTC buses are asked to assign the importance of all the twenty attributes in one questionnaire in terms of five descriptors: extremely important (A), very important (B), important (C), moderately important (D) and less important (E). The same passengers are asked to rate the level of satisfaction of the existing service qualities with respect to all the twenty attributes in another questionnaire, in terms of five descriptors; very high/very good, high/good, moderate, low/poor and very low/very poor.

The attributes for which higher values represent higher level of satisfaction (e.g. punctuality-percentage of arrivals and departures in time) have been rated as very good = A, good = B, moderate = C, poor = D and very poor = E. And the attributes for which lower values represent higher level of satisfaction (e.g., noise level) have been rated as very low = A, low = B, moderate = C, high = D, very high = E. The guideline values for rating different service qualities are given in Appendix-II. . The data obtained is processed with the help of dBASE-IV. There are 491 and 492 usable data for the city and the district services respectively.

Passengers opinion in linguistic expressions, are then averaged. The results shown in Table 2, represent a weighted average opinion on weightages of attributes for city service, on a conventional rating scale of 2-10, with 10 being the extremely important and, a non-fuzzy input (at = 1.0) by fuzzy set approach. On similar procedure, the weights of attributes for district service are also calculated and the results are shown in Table 3.

From the survey, the averaged rating of the service qualities as a group of non-fuzzy input is also presented in Table 3.The obtained results of LOPTS for city and district services, by fuzzy set approach is shown in Table 4. The service level of the attributes and its deficiency from acceptance levels as indicated by the negative sign as per numerical rating technique are presented in Table-5.

Summary and Conclusions

An approach for quality management in STUs, by using service quality survey data is presented. This approach details about ratings for twenty attributes of service quality and weights among them, fuzzy-set representations of the linguistic grades and fuzzy mathematics and the definition of LOPTS and its use in a service quality data base. The bus service quality and the weights among them are established through an extensive opinion survey and experience of a significant number of passengers of STU buses. A composite index is derived, aggregating the attributes defining the quality of service. The deficiencies of the various attributes from the acceptable levels are also quantified through numerical rating approach. The results of fuzzy approach and the conventional numerical rating approach are compared.

For all symmetrical membership functions (whether linear or non-linear), the answer will be the same by the numerical rating approach and fuzzy set approach. So the use of a single numerical rating as a mean value

Table 2. Relative Weights of Various Attributes for City Service

Attributes	No.of passengers putting weights on					Average Weights		
	A	B	C	D	E	By Fuzzy approach (Non-fuzzy input at α=1) (1)	By Numerical rating approach (2)	Relative weights from (2) $\bar{X}_i / \Sigma \bar{X}$
1. Ao (Access at origin	32	176	233	30	20	(.67, .67)	6.70	0.0463
2. W(Waiting time)	39	124	175	15	4	(.70, .70)	7.00	0.0483
3. Q(Quality of busstops and availability of bus shelters	87	215	172	15	2	(.75, .75)	7.50	0.0518
4. Fy(Frequency)	75	278	131	6	1	(.77, .77)	7.72	0.0533
5. R(Regularity/ reliability)	68	268	150	5	0	(.76, .76)	7.62	0.0526
6. P(Punctuality)	49	270	161	11	0	(.75, .75)	7.46	0.0513
7. EE(Ease of Exit and Entry)	29	174	256	30	2	(.68, .68)	6.80	0.0470
8.EM(Easeof passenger movement)	33	169	256	28	5	(.68, .68)	6.80	0.0470
9. SA(Space/seat availability)	39	224	203	20	5	(.71, .71)	7.10	0.0490
10.Ct(Comfort level of seats)	45	188	227	27	4	(.70, .70)	6.98	0.0482
11.CC(Condition and cleanliness of bus	63	244	158	25	1	(.74, .74)	7.40	0.0511
12.B(Behaviour of Conductors and Drivers)	53	196	212	22	8	(.71, .71)	7.08	0.0489

Table 2 continued...

13.Fe(Fare)	36	183	239	22	11	(.69, .69)	6.86	0.0474
14.Sd(Speed)	25	97	210	24	1	(.67, .67)	6.66	0.0460
15. N(Noise level)	88	216	146	31	10	(.74, .74)	7.38	0.0510
16. J(Jerk)	82	206	174	21	8	(.74, .74)	7.36	0.0508
17. Sy(Safety)	331	127	29	2	2	(.92, .92)	9.18	0.0634
18.RI(Route information and stop announcement)	68	268	150	5	0	(.76, .76)	7.62	0.0526
19.T(Easeof obtaining transfers)	33	189	233	32	4	(.69, .69)	6.88	0.0475
20.Ad(Access at destination)	32	176	233	30	20	(.67, .67)	6.70	0.0463

Note: The other group of non-fuzzy inputs for average weights,at $\alpha = 0.5$ and $\alpha = 0$ are given in Table 3

Table 3. Group of Non-fuzzy Inputs for Average Weights and Service Quality Rating

			Attributes of the Level of Service									
Type of service	R_I / W_I	α - Cut Intervals	A o	W	Q	Fy	R	P	EE	EM	SA	Ct
City Service	Average	α=1	.67, .67	.70,.70	.75,.75	.77, 77	.76,.76	.75,.75	.68,.68	.68,.68	.71,.71	.70,.70
	Weights	α=0.5	.52, .76	.56,.79	.61,.83	.63,.86	.62,.85	.60,.84	.53,.77	.53,.77	.57,.80	.55,.79
	(W_I)	α=0	.38, .86	.41,.88	.47,.92	.49,.94	.48,.93	.46,.93	.39,.87	.39,.87	.42,.89	.41,.88
	Av. service	α=1	.55, .55	.53,.53	.52,.52	.54,.54	.64,.64	.61,.61	.61,.61	.60,.60	.59,.59	.58,.58
	quality	α=0.5	.41, .65	.39,.63	.38,.62	.40,.64	.49,.74	.47,.71	.46,.71	.45,.70	.44,.68	.43,.68
	rating (R_I)	α=0	.27, .75	.24,.73	.23,.72	.25,.74	.35,.84	.32,.81	.31,.81	.30,.80	.29,.78	.28,.77
District Service	Av.	α=1	.68, .68	.73,.73	.75,.75	.76,.76	.77,.77	.75,.75	.70,.70	.68,.68	.73,.73	.74,.74
	weights	α=0.5	.53, .77	.59,.82	.61,.84	.62,.85	.63,.86	.60,.84	.56,.80	.53,.78	.59,.82	.59,.83
	(W_I)	α=0	.38, .87	.45,.90	.47,.92	.47,.94	.49,.95	.46,.93	.41,.89	.39,.87	.44,.91	.45,.92
	Av. service	α=1	.61, .61	.58,.58	.60,.60	.60,.60	.68,.68	.65,.65	.65,.65	.63,.63	.62,.62	.61,.61
	quality	α=0.5	.46, .70	.44,.68	.46,.70	.46,.70	.53,.78	.51,.75	.50,.75	.49,.73	.47,.72	.46,.70
	rating (R_I)	α=0	.32, .80	.29,.78	.31,.79	31,.79	.38,.87	.36,.85	.35,.85	.34,.83	.32,.82	.31,.80

Table 3. continued...

Type of service	R_I / W_I	α - Cut Intervals	Attributes of the Level of Service									
			CC	B	Fe	Sd	N	J	Sy	RI	T	Ad
City Service	Average Weights (W_I)	α=1	.74,.74	.71,.71	.69,.69	.67,.67	.74,.74	.74,.74	.92,.92	.76,.76	.69,.69	.67,.67
		α=0.5	.60,.83	.56,.80	.54,.78	.52,.76	.60,.82	.59,.82	.80,.95	.62,.85	.54,.78	.52,.76
		α=0	.45,.91	.42,.89	.40,.87	.38,.85	.46,.90	.45,.90	.69,.98	.48,.93	.40,.87	.38,.86
	Av. quality rating	α=1	.56,.56	.65,.65	.57,.57	.60,.60	.45,.45	.47,.47	.70,.70	.65,.65	.58,.58	.59,.59
		α=0.5	.42,.66	.50,.74	.42,.67	.45,.70	.31,.55	.32,.56	.56,.79	.50,.75	.43,.68	.45,.69
		α=0	.27,.76	.35,.84	.27,.77	.30,.80	.17,.65	.18,.66	.41,.88	.36,.84	.28,.77	.30,.79
District Service	Av. weights (W_I)	α=1	.78,.78	.72,.72	.69,.69	.72,.72	.78,.78	.77,.77	.93,.93	.77,.77	.70,.70	.68,.68
		α=0.5	.64,.86	.57,.81	.54,.79	.57,.81	.64,.86	.63,.85	.82,.96	.63,.86	.56,.79	.53,.77
		α=0	.50,.94	.43,.90	.39,.88	.43,.90	.50,.93	.49,.93	.70,.99	.49,.95	.41,.89	.38,.87
	Av. quality rating	α=1	.64,.64	.68,.68	.58,.58	.62,.62	.53,.53	.52,.52	.74,.74	.66,.66	.62,.62	.61,.61
		α=0.5	.49,.74	.53,.77	.43,.68	.47,.72	.38,.62	.37,.62	.59,.83	.51,.75	.47,.72	.46,.71
		α=0	.35,.83	.38,.87	.28,.78	.32,.82	.24,.72	.23,.72	.45,.92	.36,.85	.32,.82	.31,.80

Table 4. Group of Non-fuzzy Outputs for Overall Rating and Composite Index.

Type of service	Overall rating (R)	α-cut intervals	Non-fuzzy outputs	Composite Index (LOPTS)
		$\alpha = 1$	(.58, .58)	
City service	$\Sigma (R_I \times W_I)/\Sigma W_I$	$\alpha = 0.5$	(.44, .68)	0.56
		$\alpha = 0$	(.30, .78)	
		$\alpha = 1$	(.62, .62)	
District service	$\Sigma (R_I \times W_I)/\Sigma W_I$	$\alpha = 0.5$	(.48, .72)	0.60
		$\alpha = 0$	(.33, .82)	

Table 5. Service Levels and their Deficiencies from Acceptance Levels as per Numerical Rating Approach

Service Attributes	Ao	W	Q	Fy	R	P	EE	EM	SA	Ct
Relative Weight (1) (Scale value)	.0463	.0483	.0518	.0533	.0526	.0515	.0470	.0470	.0490	.0482
Service Quality (2) (with respect to unity)	.554	.532	.522	.540	.640	.608	.608	.598	.586	.576
$LOPTS_I$ (3) = (1) x (2)	.0257	.0257	.0270	.0288	.0377	.0313	.0286	.0281	.0287	.0278
Acceptance level (4) (60% of scale value)	.0278	.0290	.0311	.0320	.0316	.0309	.0282	.0282	.0294	.0289
Sufficiency/ Deficiency (-) from accepta-nce level (3) - (4)	-.0021	-.0033	-.0041	-.0032	.0021	.0004	.0004	-.0001	-.0007	-.0011
Relative weight (1) (scaleValue)	.0457	.0493	.0507	.0512	.0520	.0504	.0474	.0458	.0495	.0499
Service Quality (2) (with respect to Unity)	.608	.584	.602	.600	.680	.654	.648	.634	.618	.608
$LOPTS_I$ (3) = (1) x (2)	.0278	.0288	.0305	.0307	.0354	.0330	.0307	.0290	.0306	.0303
Acceptance level (4) (60% of scale value)	.0274	.0296	.0304	.0307	.0312	.0302	.0284	.0275	.0297	.0299
Sufficiency/ Deficiency (-) from acceptance level (3) - (4)	.0004	-.0008	.0001	0	.0042	.0028	.0023	.0015	.0009	.0004

Table 5 continued...

Service Attributes	CC	B	Fe	Sd	N	J	Sy	RI	T	Ad	Overall LOPTS
Relative Weight (1) (Scale value)	.0511	.0489	.0474	.0460	.0510	.0508	.0634	.0526	.0475	.0463	For City Service
Service Quality (2) (with respect to unity)	.562	.646	.566	.602	.455	.466	.702	.650	.576	.594	
$LOPTS_I$ (3) = (1) x (2)	.0287	.0316	.0268	.0277	.0232	.0237	.0445	.0342	.0274	.0275	Σ(3)= .58
Acceptance level (4) (60% of scale value)	.0307	.0293	.0284	.0276	.0306	.0305	.0380	.0316	.0285	.0278	
Sufficiency/ Deficiency (-) from accepta-nce level (3) - (4)	-.0020	.0023	-.0016	.0001	-.0074	-.0068	.0065	.0026	-.0011	-.0003	
Relative weight (1) (scaleValue)	.0527	.0483	.0464	.0484	.0524	.0520	.0628	.0520	.0473	.0457	For District Service
Service Quality (2) (with respect to Unity)	.640	.676	.582	.624	.528	.520	.736	.656	.620	.608	
$LOPTS_I$ (3) = (1) x (2)	.0337	.0327	.0270	.0302	.0277	.0270	.0462	.0341	.0293	.0278	Σ (3) = .62
Acceptance level (4) (60% of scale value)	.0316	.0290	.0278	.0290	.0314	.0312	.0377	.0312	.0284	.0274	
Sufficiency/ Deficiency (-) from acceptance level (3) - (4)	.0021	.0037	-.0008	.0012	-.0037	-.0042	.0085	.0029	.0009	.0004	

to each descriptive term, for symmetrical membership functions is recommended, as the calculation is simpler. But for the unsymmetrical membership functions (for both linear and non-linear), the use of fuzzy sets will yield to accurate results, as it accounts for the actual unsymmetrical variation. The membership functions assumed here are unsymmetrical in nature except for the letter grade E. So, the result obtained through fuzzy set approach is the accurate one. Thus, the fuzzy set approach which accounts for the uncertainty associated with quantification of the linguistic or letter grade has shown its potential application to public transport undertakings for assessing level of service.

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Appendix I

Examples Illustrating Fuzzy Computations in This Paper

This appendix details the fuzzy computations defined in (1) and the LOPTS defined in (2). The computation process is described in the following step-by-step procedure, Dong (1987).

1. Select a group of - cut values needed for defuzzifying a fuzzy set. In most case, the use of 11 α - cut values from 0.0 to 1.0 with an increment of 0.1 to defuzzify a fuzzy set is accurate enough. In this example, for simplicity, only three values - 0.0, 0.5 and 1.00- are used.
2. For α = 0.0, obtain the α - cut interval for each of the input fuzzy sets. According to the membership function defined in Table-1 and Fig.1, the following - cut intervals can be obtained for the given input fuzzy sets (Refer Fig.4 for α - cut concept).

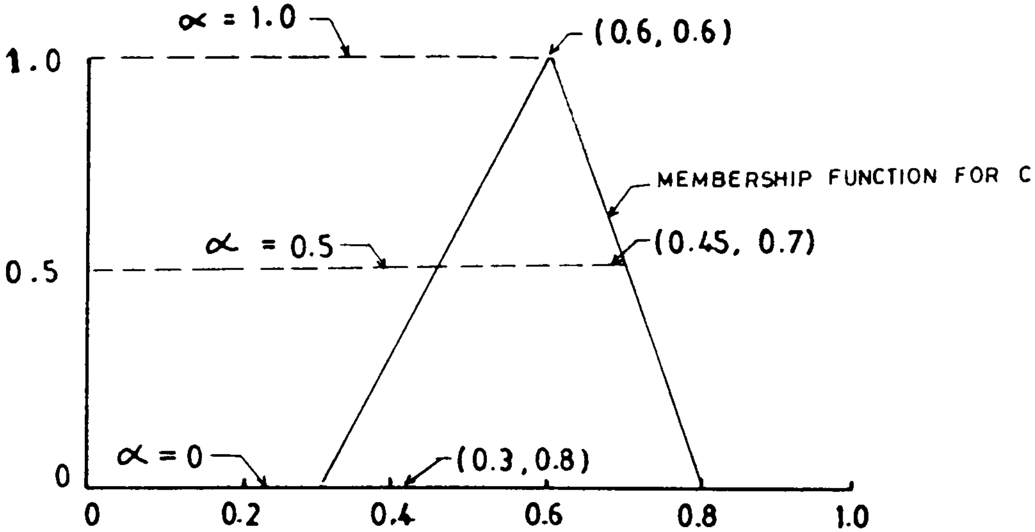

Figure 4. Cut Concept for Defuzzification

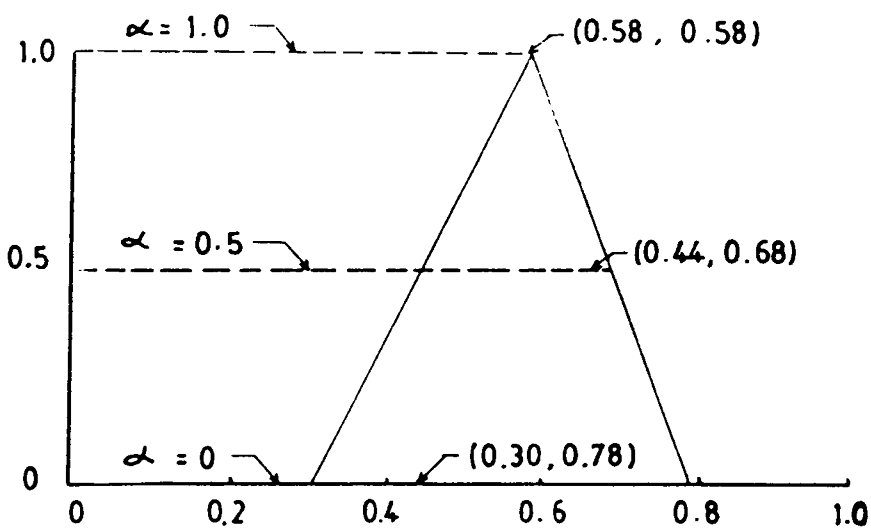

Figure 5. Resulting Fuzzy Set Obtained for Example in Appendix - I.

A group of non-fuzzy input for various letter grades at different α - cut intervals:

Letter grade	for α = 0	α = 0.5	α = 1
A	(.8, 1)	(.9, 1)	(1, 1)
B	(.5, 1)	(.65, .9)	(.8, .8)
C	(.3, .8)	(.45, .7)	(.6, .6)
D	(.1,.6)	(.25, .5)	(.4, .4)
E	(0, .4)	(.1, .3)	(.2, .2)

3. The average weightage for the attribute 1, i.e., access at origin for city service is calculated as:
   For α = 1.0

$$= \frac{32\,(1,1) + 176\,(.8,\ .8) + 233\,(.6,\ .6) + 30\,(.4,\ .4) + 20\,(.2,\ .2)}{32 + 176 + 233 + 30 + 20}$$

$$= \frac{(32,\ 32) + (140.8,\ 140.8) + (139.8,\ 139.8) + (12,\ 12) + (4,4)}{491}$$

= (328.6, 328.6)/491 = (.67, .67) (Ref. Table -2)

4. On similar lines, the average weightages and average ratings for all the attributes, for city and district services for α - cut intervals of 0, 0.5 and 1.0 are calculated and presented in Table -3.
5. Calculate R using (1) with the preceding - cut intervals. This step is essentially to perform an interval computation (Moore, 1966; Dong & Wong, 1987). Using α = 0 as an example, for city service

$$R_{\alpha=0} = \frac{[(.38,\ .86) \times (.27,\ .75) + (.41,\ .88) \times (.24,\ .73) + (.47,\ .92) \times (.23,\ .72) + \ldots\ldots\ldots + (.38\ ,\ .86) \times (.30 \times .79)]}{[(.38,\ .86) + (.41,\ .88) + (.47,\ .92) + \ldots\ldots + (.38,\ .86)]}$$

= (.30, .78)

[for example (a, b) x (c,d)/[(x,y) + (u,v)] = (axc, bxd)/ [(x+u, y+v)]
= [(axc)/(x+u) , (bxd)/(y+v)]

6. Repeat step 5 for $\alpha = 0.5$ and 1.0. This step results in $R_{\alpha=0.5}$ = (.44, .68) and $R_{\alpha=1}$ = (.58, .58) for city service. For district service, repeat step 5 for $\alpha = 0$, 0.5 and 1.0. The results are shown in Table 4.
7. The selected α values and the calculated intervals as a whole represent the resulting fuzzy set for city service and this is shown in Fig.5. The LOPTS value is calculated using (2), in a way similar to the example presented in the text.

A_l = (.30 + .58)/2 = .44
A_r = (.22 + .42)/2 = .32
LOPTS = (.44 - .32 + 1)/2 = 0.56 (Table 4)

Appendix II

Guidelines For Rating Different Service Qualities

Rating Grade	Walking distance to & from the bus stop (m)	Maximum waiting time/ frequency (min)		Reliability- % trips last to scheduled trips	Punctuality- % arrival & departure, in 5 min. from scheduled time
		City service	Dist.service		
A	≤ 100	≤ 5	≤ 10	0	100
B	101-200	6-10	11-20	.1-1.5	90-99
C	201-400	11-15	21-30	1.6-3	80-89
D	401-800	16-20	31-40	3.1-4.5	70-79
E	> 800	> 20	> 40	> 4.5	< 70

Rating Grade	For space/seat availability - % load factor		For ease of passenger movement - % load factor		Journey speed (kmph)		Noise level dB(A)
	City service	Dist.service	City service	Dist.service	City	District	
A	≤ 50	≤ 70	≤ 50	≤ 80	> 35	> 45	<60
B	51-70	71-80	51-70	81-90	31-35	41-45	60-69
C	71-85	81-90	71-85	91-100	26-30	36-40	70-79
D	86-100	91-100	86-100	101-110	21-25	31-35	80-89
E	> 100	> 100	> 100	> 110	≤ 20	≤ 30	≥ 90

Rating Grade	Bus availability at transfer point in (min)	Condition and availability of bus shelters	Ease of exit & entry	Route information & stop announcement
A	≤ 5	Bus shelter with seats in good condition	Two doors at 1/4th and 3/4th length and step height ≤ 15 cm	Available and at places
B	6-10	Bus shelter in good condition	2 doors at the front and 3/4th length and step height ≤ 15 cm	Available and on request
C	11-15	Bus shelter in moderate condition	2 doors and the step height 16-20cm	Available and at occasional stops
D	16-20	Bus shelter with poor maintenance	2 doors and the step height >20cm	Available and no announcement
E	> 20	No bus shelter	Single door and step height >20cm	Not available and no announcement