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Evaluation of Public Transport Policies Using Fuzzy Logic Techniques in Medium Sized Cities

Shaheem S*[1], Nisha Radhakrishnan[2] and Samson Mathew[3]

[1] KSCSTE – NATPAC, Thiruvananthapuram, Kerala – 695011.
[2]Department of Civil Engineering, NIT Tiruchirappalli, Tamil Nadu-620015.
[3] KSCSTE – NATPAC, Thiruvananthapuram, Kerala – 695011.

ABSTRACT

Due to India's high economic growth rate and resulting rapid urbanisation, the number of private vehicles on the road has increased dramatically. The need for developing workable transportation regulations that would help transport planners create an effective public transportation system in the city has arisen as a result of the steadily diminishing use of public transportation. The current study conducted an opinion survey in the city of Thiruvananthapuram to gather information on socioeconomic characteristics, trip details, and employee attitudes on public transportation. To further pinpoint the latent factors influencing the use of public transportation, Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) were carried out. Exploratory Factor Analysis was used to identify the latent factors, which included Reliability, Safety and Security, Comfort and Convenience. In Thiruvananthapuram city, the found latent components, socioeconomic factors, and trip characteristics were combined to construct fuzzy-logic mode choice model The effectiveness of the chosen transport policies recommended by experts was examined, both individually and collectively, by carrying out a sensitivity analysis utilising the devised fuzzy logic model. The sensitivity results showed that individual policies related to convenience and reliability will cause a mode shift from private to public transport modes of roughly 7.3% and 9.1%, respectively. Additionally, it was found that the implementation of the transportation policies related to convenience and reliability in combination will cause a mode shift of around 12.3% from private vehicles to public transportation buses.

Keywords: Mode choice models; Fuzzy logic, Public transport, Transport policies, Sensitivity analysis.

I. INTRODUCTION

During recent years, an alarming surge in the reliance on private vehicles is observed in major urban areas, which has worsened critical issues like congestion, pollution and so on. The existing public transport system needs to be improved by implementing new transport policies that would attract more commuters from personalized vehicles. Individual travel behaviour needs to be studied in greater depth to evaluate the existing public transportation system and formulate developmental strategies to improve and expand its scope for being selected for work trips. Bhaduri et al. (2020) [1] has established that individual travel behavior could be easily analyzed using mode choice modeling since mode selection is heavily impacted by human behavior characteristics. A thorough examination of mode selection decisions of commuters is beneficial in resolving challenges including projecting demand for neoteric transportation modes, reducing traffic congestion, and shifting modes because of improvements in current transportation facilities (Ortuzar and Willumsen,2011) [2].

Substandard public transport services, socio-psycho-economic characteristics of commuters, trip characteristics, private vehicle ownership appeals, other miscellaneous determinants, or a combination of the above, dissuaded people from opting public transport (Fu and Juan,2017) (Li and Cao, 2018) (Tao et al.,2019) [3-5]. Since mode choice behaviour creates a direct impact on urban transportation network’s structure and serves as the cornerstone for public transportation planning and management choices, creation of better mode choice frameworks is deemed to be a cardinal element of transportation planning.

Conventional models cannot successfully deal with the uncertainties and vulnerabilities that characterize human decisions. Soft computing approaches are relevant in terms of their ability to manage quantitative and qualitative indicators when dealing with uncertainty. As a flexible computational technique, fuzzy logic approach can be used to effectively resolve the ambiguity that exists in decision-making. The current study aims to develop mode decision models using fuzzy logic technique for work-trip information gathered from specifically Thiruvananthapuram city. The study also aims to evaluate several transport policies concentrating on ameliorating the ridership change in commuters' modes of transportation from private vehicles to public transportation.

II. LITERATURE REVIEW

An efficient public transport system is a vital component of an urban road network which ensures uninterrupted mobility of its commuters. The enhanced public transport patronage could effectively reduce the critical traffic issues such as congested corridors, alarming rate of pollution, increased journey time etc encountered in medium sized cities of India. In this context, it is necessary for the transportation planners to study the mode choice decisions of commuters for devising suitable strategies related to improving public transport patronage. The unobservable attributes of the human behaviour need to be considered along with the socioeconomic characteristics and trip attributes of the commuters for analysing the decisions related to mode choice of commuters. The study conducted by Chen and Li (2017) [6] indicated that mode choice models integrated with latent variables possess good explanatory ability and precision than the conventional models developed with only observable factors (socio-economic as well as trip related variables). Ghani et al. (2007) [7] attempted to incorporate latent factors in analysing the mode choice decisions of commuters from a town located at the outskirts of the capital city, Kuala Lumpur, Malaysia.

Conventional multinomial logit models have always found more popularity and application due to their simplicity and comparative reasonable accuracy. However, the learning capacity of the traditional models to capture complex relationships is not satisfactory which makes it difficult to capture the linguistic expressions like human behaviour. Determination of the efficacy of soft techniques to identify the complex relations in the travel patterns of the commuters has always been a keen area of interest for the researchers over the years. The study done by Minal et al. (2018) [8] proposed to capture commuters' mode-choices through exploiting an adaptive-neuro-fuzzy classifier (ANFC) with linguistic hedges. Findings suggest that soft techniques such as fuzzy logic could be employed for analyzing mode-choices in highly diversified traffic settings, wherein customary logistic regression frameworks are unable to forecast the commuter preference with enhanced accuracy. Seetharaman et al. (2009) [9] aimed at modeling the commuter's choice behavior depending on Fuzzy Logic techniques. Fuzzy logic approach overcomes the crisp input derivations and accepts linguistic expression-based multi-valued inputs, thereby, making it to mimic the unobservable/latent human behaviour attributes closely (Kedia et al., 2015) [10].

The evaluation or simulation of public transport policies is a significant component of the strategic planning process required to enhance the service of public transport system. The study conducted by Errampalli et al. (2005) [11] developed a simulation model to evaluate different public transport policies and proposed to consider mode choice behaviour in the simulation model explicitly to evaluate public transport improvement policies. The observations from the study conducted by Kumar et al., 2013 [12] indicated that fuzzy logic-oriented mode choice framework offered an acceptable flexibility in assessing any sort of transport policy regarding public transport. Pulugurta et al. (2013) [13] developed travel demand frameworks via fuzzy logic scheme considering India's Port Blair city to demonstrate fuzzy logic's superiority with regard to travel demand modeling. Naumov et al. (2020) [14] adopted fuzzy logic-directed mathematical approach to calculate the membership functions defining passengers' preference while selecting a bus path within public transportation. Fuzzy logic technique has been proven to be useful mathematical procedure for transportation and traffic process modeling, chiefly characterized by imprecision, uncertainty and subjectivity. Berbey et al., 2015 [15] employed fuzzy logic-directed approach for computing vital components of origin-terminus matrix and station's dwelling time in railway systems. Comparison of quantified dwelling time with real estimations declared that the presented fuzzy logic-directed approach exhibited good approximation. Singh et al., 2014 [16] utilized fuzzy logic for investigating commuter's satisfaction with regard to public transport for Bhopal sub-urban. Fuzzy logic technique has been proven to be a very promising mathematical approach for modelling traffic and transportation processes characterized by subjectivity, ambiguity, uncertainty, and imprecision (Sarkar et al.,2012) [17].

The extensive literature review conducted gave an indication that very few studies have been performed related to enhancement of the public transport system using soft techniques such as fuzzy logic under Indian conditions. Even though the fuzzy logic approach is an efficient means for attaining a statistically substantial passenger preference assessment with slight effort, the technique was very less used for testing of transport policies. Thus, the present study attempted to establish fuzzy logic-directed mode choice frameworks for commuters considering the Thiruvananthapuram city. The study also aimed to conduct a sensitivity analysis on the policies with the developed fuzzy logic model for identifying the relevant policies contributing to the highest shift of commuters from personalized vehicles to public transport. The scope of the study is limited to working population in Thiruvananthapuram city.

III. METHODOLOGY

Even though Thiruvananthapuram city's transportation system is well-developed with roadways, railways, waterways and an international airport, the city has witnessed a continual decline of the commuters using public transport owing to the increase in the personal vehicles. In this context, it is pertinent to gain insights into the mode choice decisions made by commuters in Thiruvananthapuram city. Moreover, the city is an epitome of a developing city with high working population which in turn meets the requirements of the ideal study area for the present study. The city limits of Thiruvananthapuram, capital of Kerala, is chosen as the study area for the present study. **Fig. 1** portrays the present work's implementation flow.

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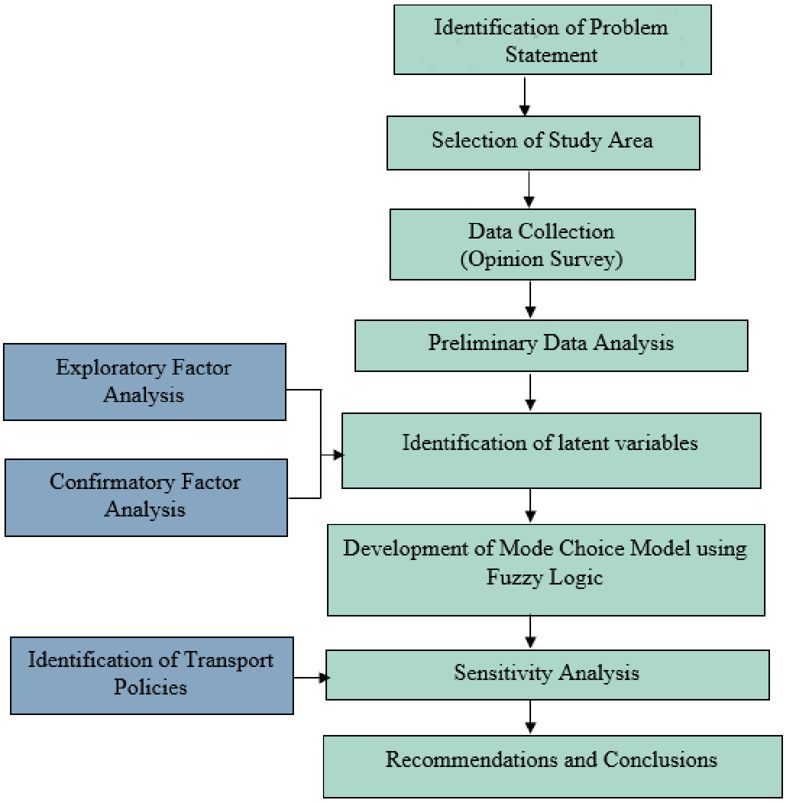

Fig. 1 Methodology adopted in current study

Data collection for current study was done by employing Opinion Survey. It was conducted in the major Government organizations as well as private offices within the precincts of the city. Consequently, prior to data collection, the minimum sample size required for the study was calculated using Cochran formula for large populations.

Cochran Formula for large populations:

$$n_o = \frac{z^2 \, p \, q}{e^2}$$

where,

n_o = Sample size
z = Corresponding value in Z table at given confidence level
p = Estimated proportion of an attribute present in the population
q = 1 – p
e = desired level of precision

In large populations, we cannot know the variability, therefore recommended values are used:

p = 0.5 (max. variability)
e = ± 3%
95% confidence level

$$n_o = \frac{(1.96)^2 * (0.5) * (0.5)}{(0.03)^2}$$

$$= 1065 \text{ samples (minimum)}$$

After data cleaning, a total of 2047 respondents were analysed for gaining an understanding related to the existing socio-economic characteristics of the commuters and travel patterns of city's all viable modes. The questionnaire designed for opinion survey consisted of three sections:

1) The socioeconomic attributes such as gender, gross monthly income, age, vehicle ownership, and household size.
2) Trip related variables such as travel distance, preferred means of transportation to work, total journey time and travel cost.
3) Indicator variables (IVs) reflecting attitude of commuters towards public transport which were to be rated by the commuters themselves on a five-point scale.

The rating obtained related to indicator statements in the questionnaire was subjected to Exploratory Factor Analysis (EFA) for identifying the major latent constructs influencing the attitude of commuters towards public transport. Confirmatory Factor Analysis (CFA) was done as the next step to verify if the observed variables are representative of the latent factors identified through EFA. The identified latent constructs were integrated with the significant socio-economic as well as travel characteristics of commuters in Thiruvananthapuram city for developing mode choice models based on fuzzy logic technique. An expert opinion survey was conducted to choose relevant public transport improvement policies for attracting commuters from private vehicles to public transport. The selected transport policies were then subjected to sensitivity analysis using fuzzy logic model for identifying the probable mode shift from private modes to public transport modes in Thiruvananthapuram city.

IV. PRELIMINARY DATA ANALYSIS

The data acquired through the Opinion Survey was subjected to preliminary data analysis using the SPSS software. The analysis process helped in gaining an understanding about major socio-economic characteristics as well as travel attributes of the commuters. **Table 1** summarises the socio-economic characteristics of commuters working in Thiruvananthapuram City.

Table 1 Socio-economic characteristics of commuters working in Thiruvananthapuram City

Variables	Subcategories	Sample distribution (%)
Gender	Male	50.5
	Female	49.5
Age	18 - 30	23.6
	31 - 40	33.2
	41 - 50	27.9
	51 - 60	13.0
	61 - 65	1.7
	>65	0.6
Monthly income	Rs 0- 10,000	6.0
	Rs 10,000 – 20,000	24.6
	Rs 20,000 – 30,000	25.6
	Rs 30,000 – 50,000	27.4
	Rs 50,000 – 1,00,000	13.9
	> Rs 1,00,000	2.5
Vehicle Ownership	Yes	83.4
	No	16.6

The distribution of work trips based on travel mode is shown in **Fig.2.** It was found that the largest commuter share chose two-wheeler for their work trips (42%), followed by bus (33%) and car (15%).

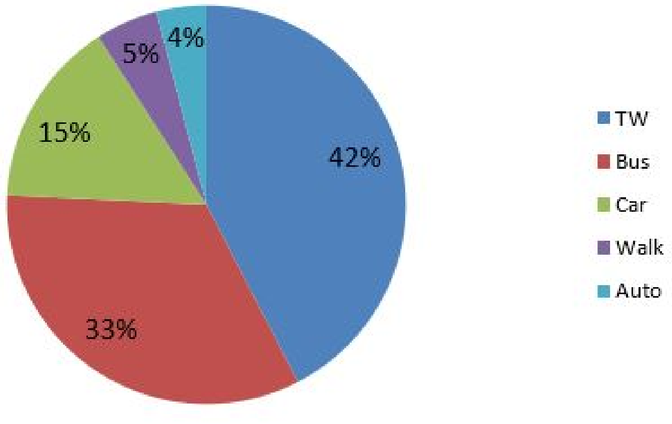

Fig.2 Mode-wise distribution of trips

It was found that majority (76%) of the commuters performing work trips have their total trip distance less than 20 km. It was also observed that majority of the female commuters prefer public transport for the work trips whereas two-wheeler is chosen by majority of the male commuters. Another significant observation was that mode choice decisions of workers were significantly influenced by travel distance. Walking is typically the highlypreferred mode for short distance travel (less than 500m), whereas bus is normally the highly preferred mode for long haul travel (more than 20 km). In other words, there is greater probability of commuters choosing public transport as the distance of the trip increases.

V. FACTOR ANALYSIS

Factor analysis is a statistical tool that helps to determine latent or hidden variables from a set of correlated observed variables. EFA using varimax rotation was the first step done as part of factor analysis to discover the fundamental relationship between indicator variables and latent attributes. The number of latent factors was fixed based on Eigenvalue which is a measure of how much of the common variance of the observed variables is explained by a particular factor. The present study fixed the number of factors based on the principle that these identified factors have their Eigen value greater than or equal to 1. It was observed from the rotated component matrix that there were four latent factors with Eigen value greater than or equal to 1. Only 13 variables were retained out of a total of 20 indicator variables included in the questionnaire. Reliability, Safety and Security, Comfort and Convenience were obtained as the four major latent constructs influencing the attitude of commuters towards public transport.

CFA was the second step and was done to verify how well the quantified variables denote the count of latent constructs. The major advantageous aspects of CFA are that it enables the researchers independently to specify the number of factors required in the data as well as to select the measured variable which needs to be related to a specific latent variable. CFA was used to either confirm or reject a specific measurement theory. Model fit indices indicate how well the data used for developing the models represents the underlying measurement theory. **Fig. 3** shows the path diagram of Confirmatory Factor Analysis. **Table 2** gives the values of model fit indices obtained from CFA.

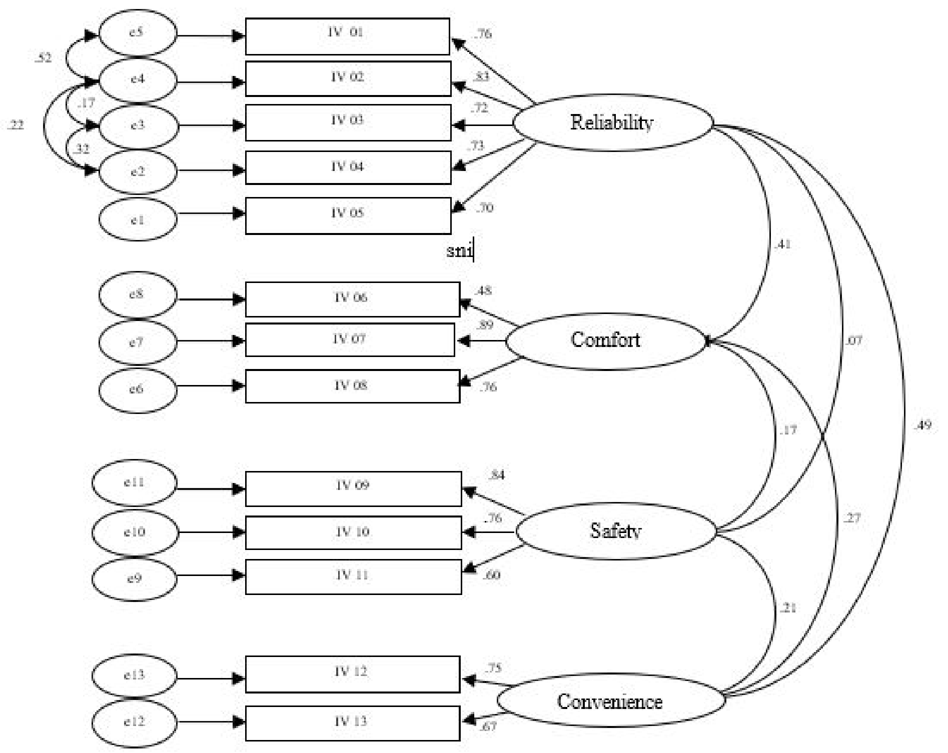

Fig. 3 Path diagram of Confirmatory Factor Analysis

The degrees of freedom (DF) indicate the number of independent values that vary in an analysis without breaking any constraints. The present work obtained a value of CMIN/DF of 4.97(<5) which in turn indicated an acceptable model fit. The value of Root Mean Square Error of Approximation (RMSEA) ranges from 0 to 1, with an acceptable value when it is less than 0.06. In the present work, a value of 0.054 was obtained which indicated an acceptable model fit.

Table 2 Values of Model fit indices obtained from confirmatory factor analysis

Parameters	Acceptable values	Observed values
CMIN/DF)	<5	4.97
RMSEA	<=.06	0.054
GFI	>0.9	0.971
AGFI	>0.85	0.952

It was observed from the above table that the model fit indices considered for the study were within the acceptable limits. Thus, CFA verified the relation between observable attributes and latent constructs.

VI. DEVELOPMENT OF MODE CHOICE MODEL

The conventional mode choice techniques are found to be less effective in successfully dealing with the uncertainties and vulnerabilities in human decisions, whereas soft computing approaches are relevant in terms of their ability to manage quantitative and qualitative indicators when dealing with uncertainty. Conventional mode choice modelling techniques need crisp input variable values that are hard to gather and consume more energy and time. Soft techniques do not typically require crisp input values as they consider human mind's uncertainty via acknowledging input variables exploiting fuzzy membership functions. There are many soft techniques that could be employed to develop mode choice models such as Artificial Neural Network (ANN) and Fuzzy Logic Method. The inability to interpret the outcome of the process in terms of rules has been added to the black box nature of ANN which has been identified as one of its major drawbacks. Fuzzy Logic is an intelligent approach with easiness to understand as well as implement by providing a user-friendly approach of presentation. The modelling of imprecise knowledge and unambiguity transmission is possible using fuzzy logic (Kumari and Sunita, 2013) [18]. Hence, the present study has adopted fuzzy logic technique to develop mode choice models in Thiruvananthapuram city owing to its "user-friendly" and efficient performance.

VII. FUZZY LOGIC-ORIENTED MODE CHOICE FRAMEWORK

7.1 General

Fuzzy logic involves mathematical concepts of set theory and provides the most effective solution to tedious problems in all disciplines of life as it mimics human decision making and reasoning. The fuzzy logic theory is reliant on the notion of relative graded membership, as inspired by the processes of human perception and cognition (Singh et al, 2013) [19]. As previously stated in the literature review, fuzzy logic techniques can accurately simulate fuzziness or vagueness in the input variables to provide results with precision. Here, mode choice framework for the present study was developed using a MATLAB as the working platform, which provided a user-friendly Graphical Interface. The total sample of data acquired from working population of Thiruvananthapuram metropolitan was categorized into four groups based on vehicle ownership: no vehicle, two-wheeler only, car only, and both two-wheeler and car owning groups. The fuzzy logic system structure is displayed in **Fig. 4.**

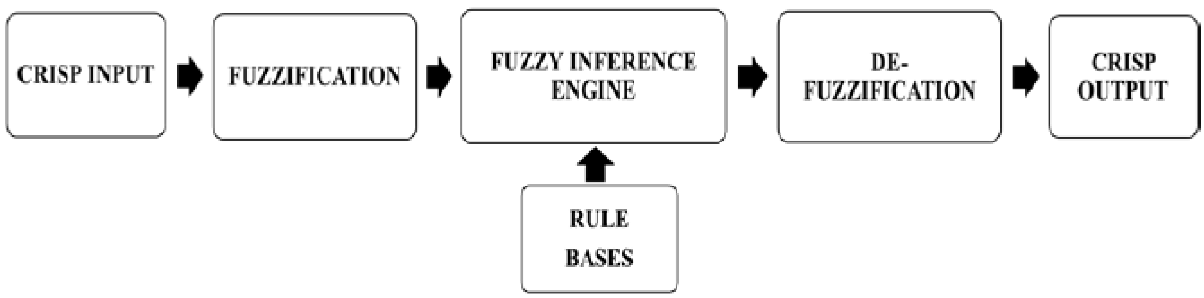

FIG.4 PROPOSED FUZZY LOGIC-ORIENTED SYSTEM STRUCTURE

7.2 Fuzzification

Generally, crisp sets were found to define the input variables analysed in traditional mode choice models which made it rather difficult to explore the complex human decision-making processes. Fuzzification enables translation of crisp input values to linguistic variables defining complex human behaviour. The input variables selected for mode choice modelling were monthly income, distance from residence to workplace, gender, age, travel cost, comfort, reliability, safety and security and convenience of public transport. The input variables were identified based on their significance as observed in the opinion survey conducted among employees in Thiruvananthapuram city for the present study. Car, bus, two-wheeler, auto-rickshaw, and walk were the major modes observed to be chosen by commuters mainly for their work trips. Hence, the output variables related to the model were the utility functions associated with auto-rickshaw, walk, two-wheeler, bus and car.

7.3 Setting of Membership Functions

The input variables collected by means of Opinion Survey were in crisp form which required to undergo fuzzification via suitable membership functions (MF). Based on literature review conducted related to fuzzy logic modelling, triangular membership function was adopted for all the input attributes except ‘Gender’. Sadollah (2018) [20] has stated that triangular MFs are straight line membership functions having the advantage of simplicity. Calculations are comparatively much easier with triangular membership function as it is defined by only three values, i.e., a lower limit value, an upper limit value and a peak value which lies between lower and upper limit values. Trapezoidal function was used for gender since the variable assumes only two values: male and female. The membership functions enable graphical representation of fuzzy sets and allocates a value lying between 0 and 1, called ‘membership value’ or ‘degree of membership’ for every input within a specific range. Moreover, the triangular membership functions were provided in such a way that there is an overlapping between every membership function to avoid missing out of any intermediate values in between the functions. The membership function plot set for bus utility is shown in **Fig. 5**. Level of membership functions selected for input and output variables is given in **Table 3**.

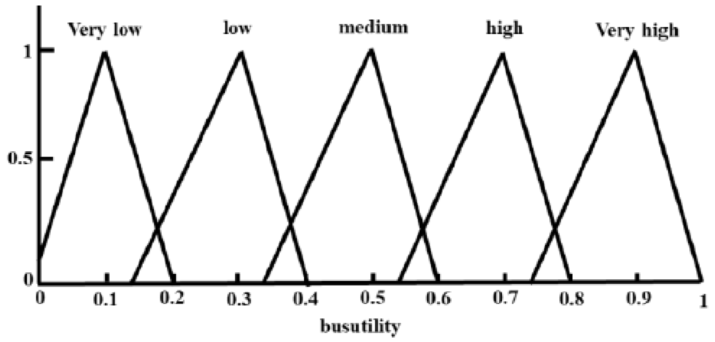

Fig.5 Membership function for Bus Utility

Table 3 Level of membership functions for input and output variables

Variables		**Membership Functions**
Input Variables	Travel Time	Very low [0 10 20], Low [10 20 30], Medium [20 35 50], High [45 60 75], Very high [60 90 120]
	Monthly Income (in Rs)	Very low [0 5000 10000], Low [6000 12000 20000], Medium [14000 27000 40000], High [35000 58000 80000], Very high [60000 130000 200000]
	Age (in years)	Very young [18 24 30], Young [25 33 40], Middle age [35 43 50], Senior age [45 53 62], Elder [55 60 65]
	Distance from residence to workplace (in km)	Very short [0 0.5 1], Short [0.75 2.5 5], Medium [4 7 10], Long [8 14 20], Very long [18 34 60]
	Gender	Male [0 0 1 1.5], Female [1.5 1.5 1.75 2]
	Travel cost (in Rs)	Very low [0 15 35], Low [25 38 50], Medium [42 72 100], High [75 115 150], Very high [135 320 500]
	Comfort/Reliability/Safety & security/ Frequency of public transport	Very low [0 2.5 5], Low [3 5 10], Medium [5 10 15], High [10 15 20], Very high [15 20 25]
Output Variables	Bus utility/Auto rickshaw utility/ Car utility/ Two-wheeler utility/ Walk utility	Very low [0 0.1 0.2], Low [0.15 0.3 0.4], Medium [0.35 0.5 0.6], High [0.55 0.7 0.8], Very high [0.75 0.9 1]

7.4 Fuzzy Inference System (FIS)

FIS refers to the processing section of the input variables to form the output. The fuzzified input variables were input to a fuzzy inference (FI) engine consisting of “if-then” rules, wherein product-sum gravity scheme was used to produce result in linguistic form. Further, these rules were formulated based on the trend followed by the data during preliminary analysis as well as by employing logical thinking and general experience. Rules were formed using ‘Rule editor’ window of fuzzy logic toolbox and every possible combination of rules were explored based on prevailing mode choice decisions made by commuters. In this study, four rule bases were formed separately for the four vehicle owning groups by considering combinations of two input variables at a time. A total of 3120 IF -THEN rules were formulated for obtaining the final combined fuzzy logic model. For example, in case of no vehicle owning group, a rule was formulated such as "IF distance is very short and age is very young THEN bus utility is very low, walk utility is very high, auto rickshaw utility is very low".

7.5 Defuzzification

The process of conversion of fuzzified linguistic output back into crisp values is called defuzzification. In this study, the centroid method was adopted for defuzzifying as it is one of the easiest methods in which the centre of area of the fuzzy set was determined and corresponding crisp value was returned as output. In the present study, the defuzzified output values, which corresponded to the utility of available modes chosen by commuters were obtained in the range between 0 to 1. The mode with highest utility value was to be considered as predicted mode of each respondent.

7.6 Determination of Prediction Accuracy

7.6.1 Calibration

Calibration is a significant step in the fuzzy logic modelling process as it enables the mode choice model to accurately reflect the real time commuting patterns as well as to facilitate simulation of proposed policies with precision. It was done by considering two-third of the data obtained by conducting Opinion Survey. The calibration was performed separately for each categorized vehicle ownership groups and the probable mode predicted for each commuter was compared with the observed mode to determine both the valid and non-valid predictions obtained in the process. The results of individual models developed separately for each vehicle owning group were combined to obtain the final combined calibrated model. The calibrated model's prediction accuracy was determined to be around 71% which was within the acceptable limit. **Table 4** summarises the output of calibrated model.

Table 4 Output of Calibration Model

MODE	Bus	Walk	Auto rickshaw	Two-wheeler	Car	Total Observed
Bus	**239**	4	10	165	53	471
Walk	22	**25**	1	24	. 2	74
Auto rickshaw	13	1	**23**	13	9	59
Two-wheeler	11	6	3	**461**	30	511
Car	4	0	0	11	**200**	215
Total predicted	289	36	37	674	294	**1330**
Prediction accuracy	[(239+25+23+461+200)/1330] *100 = 71%					

7.6.2 Validation

Validation of the model was done by considering the remaining one-third of the data which was not used for calibration process. The dataset was taken for validation into the same inference system and prediction accuracy was checked as mentioned above in the process of calibration. Validation was also conducted separately for each vehicle ownership groups and finally the results were accumulated into a combined model. The accuracy of prediction of the obtained validation model was about 74%, which was closer to the accuracy of calibration model (71%). **Table 5** summarises the output of validation model.

Table 5 Output of validation model

MODE	**Bus**	**Walk**	**Auto rickshaw**	**Two-wheeler**	**Car**	**Total Observed**
Bus	**145**	1	1	46	28	221
Walk	4	**12**	0	8	10	34
Auto rickshaw	8	0	**10**	3	2	23
Two-wheeler	37	2	1	**281**	22	343
Car	1	0	0	12	**83**	96
Total predicted	195	15	12	350	145	**717**
Prediction accuracy	[(145+12+10+281+83)/717] *100 = 74%					

VIII. IDENTIFICATION OF POLICIES FOR PUBLIC TRANSPORT ENHANCEMENT

As stated in preliminary analysis, more than half of the employees in Thiruvananthapuram city use personalized vehicles for their work trips which have inevitably worsened the issue of severe congestion. Hence, identification of relevant as well as feasible policies is considered significant to encourage shift of commuters from private vehicles to public transport system.

An expert opinion survey was conducted involving professionals specialized in the area of transportation engineering, including scientists, researchers, experienced academics and transportation practitioners to select the most relevant and viable policies from among the total suggested policies. The current study proposed a total of 25 policies which were categorized into three sections: Public transport improvement measures, Private Vehicle Ownership Related Measures and Private Vehicle Usage Related Measures. The policies were compiled into a questionnaire, which was distributed through Google forms to the selected experts. The experts were asked to rate the feasibility and relevance of strategies on a scale of 1 to 5, 1 being not at all feasible/relevant and 5 being very relevant/feasible. A total of 50 responses were collected using Google forms from experts. A total of four policies, which were rated 4 and 5 by more than 50% of experts, were identified for sensitivity analysis:

- Policy 1: Real-time bus information using smart phone application
- Policy 2: Providing cameras inside the bus for security and safety
- Policy 3: Passenger waiting areas/shelters with comfortable seating at bus stops
- Policy 4: Improving public transport coverage and supply

IX. EVALUATION OF TRANSPORT POLICIES

The effectiveness of policies is determined based on the proportion of commuters being attracted to public transport from private vehicles. Thus, sensitivity analysis needs to be performed for assessing the mode shift that occurs because of the implementation of the policies. The foremost task in sensitivity analysis was to identify the underlying relevant latent variable related to each identified policies obtained from the expert opinion survey. Reliability, Safety, Comfort and Convenience were the underlying variables identified related to Policy 1, Policy 2, Policy 3 and Policy 4 respectively. The latent variables were subjected to sensitivity analysis by varying 10%, 15% and 20% respectively in order to determine the mode deviation from private vehicles to public transport under the impact of each policy. **Table 4** gives a summary of sensitivity analysis of policies.

Table 4 Summary of Sensitivity Analysis of Policies

Variation in latent attributes	Mode deviation from private to public transport			
	Policy 1	Policy 2	Policy 3	Policy 4
10%	4.9%	0.9%	0.2%	3.4%
15%	7.1%	1.3%	0.3%	4.9%
20%	9.1%	1.7%	0.5%	6.4%

It was observed that when the latent attributes associated with each policy was varied from 10% to 20%, there was an increase in public transport ridership. The maximum mode shift obtained from the sensitivity analysis of the policies varied from 0.5% to 9.1%. It was found that when the latent attributes such as comfort and safety related to public transport were increased up to 20%, there was no major shift observed from private to public transport vehicles with respect to comfort (0.5 %) and safety (1.7%). The policy 1 (real-time bus information using smart phone application) related to reliability was found to produce the highest mode shift to public transport (9.1%) followed by the policy 4 (improving public transport coverage and supply) related to convenience (6.4%).

The sensitivity analysis was also carried out for a combination of the different policies related to safety, comfort, reliability, and convenience by varying latent variables from 10% to 20%. The highest shift was observed from private vehicles to public transport while performing the combination of policies (1 & 4) related to reliability and convenience (12.3%). Since the combination of policies produces a greater shift rather than the individual policies, the study recommended to execute the policies related to reliability and convenience as a bundle for enhancing public transport ridership in Thiruvananthapuram city.

X. SUMMARY AND CONCLUSIONS

During preliminary analysis, it was found that two-wheelers and cars together formed a major proportion (57%) of the travel mode choices made by the employees working in Thiruvananthapuram city which was lesser than commuters travelling by bus (34%). Therefore, the present study attempted to recommend feasible policies for enhancing public transport ridership in Thiruvananthapuram city. Mode choice analysis was performed for work trips in the study area by employing fuzzy logic technique. It was also observed that majority of the female commuters preferred public transport for the work trips whereas two-wheeler was chosen by majority of the male commuters. Moreover, there is greater probability of commuters choosing public transport as the distance of the trip increases.

The developed fuzzy logic model was observed to have an accuracy of 71% in calibration and 74% in validation which strongly indicated that the fuzzy logic model predicts the mode choice of the commuters with an acceptable precision. The expert opinion survey identified four relevant policies related to public transport service improvement to attract more commuters from personalized modes to public transport modes. The policies selected were: Real-time bus information using smart phone application, providing cameras inside the bus for security and safety, passenger waiting areas/shelters with comfortable seating at bus stops and improving public transport coverage and supply. The selected transport policies were subjected to sensitivity analysis by scaling the related latent variable from 10% to 20% for assessing the probable mode shift to public transport.

The policy of real-time bus information using smart phone application related to reliability was found to produce the highest mode shift to public transport (9.1%) when tested individually. Since the work trips occur at maximum rate during the peak hours, it becomes economical for an employee to travel by public transport rather than paying huge amount levied on the use of private vehicles. Upgrading public transport coverage and supply also was found to cause significant mode shift to public transport (6.4%). Thus, reliability and convenience were identified as the significant latent attributes considered by the commuters undertaking work trips in Thiruvananthapuram city.

When the individual policies were tested in combination, it was found that the policies such as real-time bus information using smart phone application and increasing public transport coverage and supply were found to produce the highest mode shift (12.3%) when implemented together in a bundle. Hence, it was proposed to implement a combination of the aforementioned policies to discourage the use of private travel modes and promote the use of public transport in Thiruvananthapuram city.

The fuzzy logic models developed as part of the study offer valuable insights into the mode choice behaviour of employees by considering all the critical areas of human decision making with maximum precision. This study will serve as an aid for transport planners and policy makers to develop various policies and recommendations for improving public transport patronage in Thiruvananthapuram city. The scope of the study could be extended in the future to those commuters travelling for any other purpose other than work.

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