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Developing A Fuzzy Rule Based Urban Trip Distribution Model On Income Criteria Basis At Zonal Level: A Case Study

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Abstract: *Trip distribution as such is the process of estimating the interchange volumes between the pair of zones in a city in four step urban transportation planning process. Several conventional methods are available in literature for this purpose in growth factor or gravity based synthetic form. But they deal mostly at macro level of a city in a mechanical way and are missing the decision taking in human perception and expressions. Trip distribution modeling owe to impreciseness and vagueness. The present paper precisely focuses on this by considering Fuzzy Rule based modeling. West Zone across the river in Surat city has been considered as study area here for micro level analysis, trip productions; attractions and impedance between the sub-zones are considered as inputs for the developed model. The outcome of the model is frequency of the trips within the zone itself with reference to various income groups. It is interesting to note the variation in transport deterrence factor* ***'α'*** *to vary from 1.74 to 1.60for varied income groups in gravity model in the study. The impact of income has been realized on the trip lengths in Fuzzy Based model of the present work. The model FL-UTDM developed here shows improved results over the traditional gravity model. The model finds application in intra zonal Trip distribution while planning the modules of Neighborhoods or TP Schemes of a metropolitan city.*

Keywords – *Accessibility, Fuzzy Rule Based model, Gravity Model, Income, Urban trip distribution.*

I. Introduction

Trip distribution constitutes the second stage in the traditional transportation planning process.Trip distribution models are used to determine the number of trips between pairs of zones whenthe number of trips generated attracted by particular zones is known. Thus, the prediction of trip distribution involves the prediction of flows in a network regardless of a possible transportation mode or travel route. Traffic flows and trip distribution resulted from human choices that are affected by social and individual variables of the commuters. Due to this fact that human decision making are more consistent with fuzzy logic in comparison with crisp mathematics. It seems that fuzzy logic could be a logical tool to map such areas. Different models have been developed to forecast trip flows in recent years. The key to a successful forecasting is to recognize the existing patterns correctly. Trip distribution problem was also solved using fuzzy logic by Kalic and Teodorovic (1996). A three phase fuzzy inference system (FIS) was proposed by Jassbi et al (2011) to mapsocial and demographic variables to total number of trips between origin-destination (OD) pairs.Fuzzy rule bases in the model are in fact the exploration of transportation experts' subjectivePatterns.Basic results linked to the development of fuzzy logic date back to Zadeh (1973) and Mamdani and Assilian (1975) Introducing a concept called 'Approximate Reasoning'.

II. Study objectives

The main objective of the study is to develop the Fuzzy Rule Based Urban Trip Distribution Model (FRB-UTDM) with due consideration to income categories LIG, MIG and HIG at zonal level and compare same with conventional Gravity model.

III. Literature support

Fuzzy Logic theory was propounded by L.A. Zadeh in 1965. Fuzzy Logic based modelling gained importance to address uncertainty and linguistic expressions of attributes, wherein two types of Fuzzy Inference System (FIS) namely Sugeno and Mamdani are adopted. Mamdani FIS is more widely used, particularly for decision support applications, mostly because of the intuitive and interpretable nature of the rule base [1]. A general method to generate fuzzy rules from numerical data was proposed which later on was used by transportation researchers in trip distribution and mode choice modelling [17]. Further, an application of the fuzzy concept in representation of utility of travel mode was floated rather than considering it as a deterministic concept [12]. Fuzzy Logic proved to be very reliable soft computing technique to model the choice behavior characterized by imprecision, subjectivity, ambiguity, and uncertainty [6,8]. As per further work, Logit models with fuzzy reasoning-based utility functions can describe a human decision with vagueness explicitly [10]. Also, approximate reasoning framework as in the case of fuzzy logic shows great flexibility in capturing the decision process, e.g. nonlinear effects [13].Many researchers have explored the feasibility of applying soft computing techniques to real transportation problems. A number of studies have been carried with the concept of fuzziness. FL has proved to be a good tool for a wide range of application areas such as system/process control, pattern recognition, classification, machine learning, decision-making and approximate reasoning. It has also been proven to be very useful in nonlinear input-output mapping since, fuzzy systems can be treated as universal approximators [14, 5].As an extension of classical rule-based systems, an FRBS uses fuzzy sets and FL to represent and connect knowledge which is usually linguistic in nature. They have also been applied in many traffic and transportation studies. Traffic control and management, accident analysis and prevention, selection of transportation investments, and modeling any individual step in four stage travel demand analysis are widely known application areas of FRBSs [2, 3].

Wang and Mendel [14] developed a general method to generate fuzzy rules from numerical data. This method can be used as a general way to combine both numerical and linguistic information into a common framework – a fuzzy rule base. A pioneering fuzzy logic approach to trip distribution modeling is introduced by Kalic and Teodorovic. They estimated air passenger flows among selected major industrial cities and tourist resorts using known productions and attractions as inputs. In another study, Kalic and Teodorovic improved their results with a GFRBS (Genetic Fuzzy Rule Based System) design [16]. Discretionary trips are more flexible than compulsory trips and associated with uncertainty in decision making, modelling of discretionary trips can be well addressed by fuzzy logic [15]. Kalik, et.al. (2012) developed trip generation and distribution model using fuzzy logic. Trip generation has been considered on the country level and trip distribution between origin country and destination countries (country-pair level). Results of their research provided empirical evidence relating to successful use of fuzzy logic as a non-traditional technique [4]. Fuzzy logic can improve the model accuracy by dealing with the uncertainty in the data. Meanwhile, Artificial Neural Networks can be considered as an efficient modelling technique as it develops and calibrate the model at the same time [11].

IV. Study area

Surat city which is the second largest and fast growing industrial city in Gujarat is considered here for the study. The city of Surat (Municipal Corporation of Surat) has an area of 326.5 square kilometers and a population of 4,767,789 (2011), with a density of 15,238 persons/km². Out of the seven administrative zones of Surat city, West zone has been adopted as the study area having nearly 4, 24,986 (2011) population over an area of 51.28square kilometers. After analyzing the population data of West zone, study area is further redefined by removing variyav portion on the North side of the zone due to its meagre share of population. The study area is spread over an area of 28.8 square kilometers with 4, 05,064 population. The zone is further divided into six sub-zones namely Adajan, Rander, Jahangirpura, Jahangirabad, Pal and Palanpur for the model building and analysis purpose Figure.1.

Fig.1. Study sub-zones in West zone of Surat city

Demographic profile of the sub-zone including the population, area, household and the density are presented in the Table.1 given below.

Table.1. Demographic profile of study zone (2011)

Sub-Zone	Area(km^2)	Population	No. of HHs	Density
Adajan	6.73	1,96,850	45,993	29,249.6
Rander	5.12	1,14,586	23,290	22,380.1
Jahangirpura (JP)	3.62	27,807	5,584	7,689.9
Jahangirabad (JB)	4.16	6,221	1,567	1,495.4
Pal	6.05	36,108	9,118	5,973.2
Palanpur (PP)	3.01	23,492	5,932	7,809.8
Total	28.68	4,05,064	91,484	74,598.2

V. Methodology

The information pertaining to existing conditions with respect to urban land-use, transport system, economic activity profile, travel pattern, and socio economic characteristics of the study area is vital for any meaningful urban transportation planning exercise. The efficiency of model developed depends heavily on the calibration data used. Therefore, the collection of the field data either through primary and/or secondary source is extremely important. Home interview surveys are carried out in nearly 400 households to build the data base for the study using designed questionnaire. The data focus was on trip origin, trip destinations and trip purpose among the six sub-zones for intra zonal analysis. Trips carried from each sub-zone outside the West zone across the river to the other city area were also noted.70% of the data is used for the development of the model and rest 30% is used for testing and validation of the models.

Based on the household income the whole data were divided into three income categories LIG,MIG and HIG having income ranges less than or equal to Rs. 15000 ,between 15000 and 30000 and more than 30000 respectively. Distance Impedance Factor (DIF) **'α'** in Gravity model has been calibrated on existing trip

$$Tij = \frac{Pi\ Pj}{Dij^{\alpha}} K \quad (1)$$

Distribution pattern for three categories of income groups to find **'α'** equal to 1.60, 1.64 and 1.74 for HIG, MIG and LIG. These **'α'** are further employed in Fuzzy Model development to define accessibility levels. RMSE values on Gravity model basis has been worked out. Fuzzy Rule Based Urban Trip distribution model (FRB-UTDM) has been developed using Fuzzy Logic toolbox in MATLAB software. The performance of the models is compared with the conventional Gravity based trip distribution model.

VI. Model building

FRB-UTDM and ANN-UTDM have been developed by taking trip production, trip attraction and distance between the sub-zones which indicates the impedance to inter zonal travel, as the inputs. Model inputs and model structure of FRB-UTDM and ANN-UTDM are given in the following sections.

6.1. Model inputs

Model inputs for both the models are same, trip production; trip attraction and distance between the zones as given below.

6.1.1. Trip production/ Trip attraction

Trips going outside the study area are not considered for the development of the model. All the mandatory as well as discretionary trips are considered here. Total trip production of Low Income Group (LIG), Middle income Group (MIG) and High Income Group (HIG) are given in Table.2.

Table.2. Total trips and intra zonal trips

Income categories	Total Trips	% Trips going outside	Intra zonal Trips
LIG	187	40	112
MIG	693	45	379
HIG	609	49	309
Total	1489		800

Total intra zonal trips generated and attracted are 800 in numbers which are considered for the development of the model irrespective of income status. The trip generated and attracted on sub zonal basis are as given in Table 3.

Table.3.Zonal Productions/Attractions

Sub-Zone	Pi	Aj
Adajan	264	364
Rander	117	121
Pal	34	58
Palanpur	36	103
Jahangirpura	192	74
Jahangirabad	157	80
Total	800	800

Where:

Pi=Trip Productions
Ai=Trip Attractions

6.1.2. Trip Distances

Inter sub zonal distance in km for all the six sub zones is covered in the following Table.4. Average distance based on survey data is considered for the intra sub zonal trips. The maximum distance of 6.71 km is between Jahangirpura and Pal. The minimum distance of 1.30 km is observed between Palanpur and Jahangirabad. Lower distances are observed in a diagonal way for the intra sub zonal trips.The distances are measured between the zonal centroid.

Table.4. Inter sub zonal Distance matrix (kilometer)

Distance Matrix

Sub zones	Adajan	Rander	Pal	Palanpur	Jahangirpura	Jahangirabad
Adajan	1.50*	2.65	2.42	3.60	6.10	3.22
Rander	2.65	1.20	3.33	2.60	3.60	1.41
Pal	2.42	3.33	1.00	2.21	6.71	2.80
Palanpur	3.60	2.60	2.21	0.70	5.07	1.30
Jahangirpura	6.10	3.60	6.71	5.07	1.50	4.01
Jahangirabad	3.22	1.41	2.80	1.30	4.01	1.00

*intra sub-zone distance= i*i is considered as average trip length in km on observed data.

VII. Development of model: FRB-UTDM

7.1. Model structure

The fuzzy model structure comprises of three basic stages as shown in Figure.2.

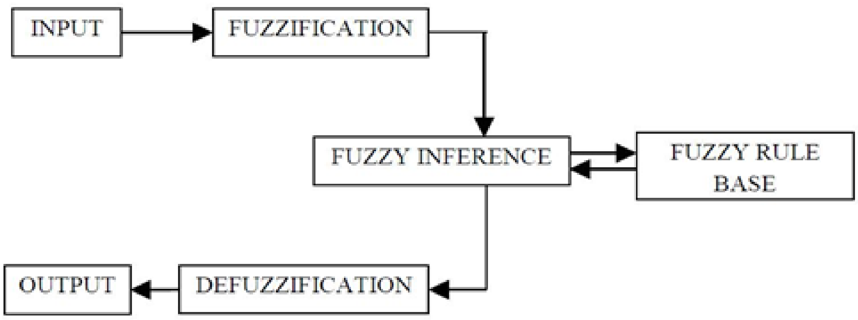

Fig.2. Fuzzy Logic system

First stage is Fuzzification, the process where the crisp quantities are converted into linguistic fuzzy set. A membership function is a mathematical expression that deals with fuzziness of a fuzzy set. Fuzzy inference system (FIS) is the second and important phase of fuzzy logic system. The FIS formulates suitable "IF-THEN" rules based upon which the decision process takes place. Third is the Defuzzification phase where the aggregated fuzzy output is converted into a crisp value ready for application.The implementation of these phases is discussed in detail in the following section.

7.2. Fuzzification

There are several shapes which can be adopted to frame membership functions such as Triangular, Trapezoidal, Gaussian, etc. Here, the shapes of the membership functions for the input variables, viz. *trip productions*, *trip attractions* and *distances between the sub-zones*, and output variable *trip interchanges* have been obtained by carrying out the fuzzy C-mean clustering algorithm available in MATLAB. All the input variables are divided into three fuzzy sets, whereas the output variable into five fuzzy sets.

Trip production is bifurcated into three clusters namely low, medium and high, and the membership values of each data point corresponding to the three clusters are obtained. Membership values of trip production are given in Table.5.

Table.5. Membership values for zonal productions

Trip productions	low	medium	high
34	0.0003	0.9995	0.0001
36	5.79E-06	0.9999	1.62E-06
117	0.7782	0.1682	0.0534
157	0.9990	0.0004	0.0005
192	0.7355	0.0425	0.2218
264	0.0011	0.0002	0.9985

Membership graphs are plotted by taking zonal productions on X-axis and degree of membership to different clusters on Y-axis as shown in Figure.3.

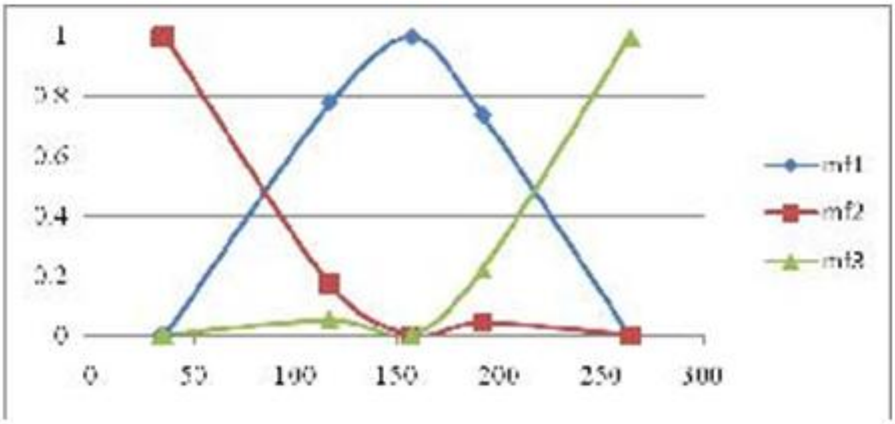

Figure.3. Obtained membership functions for zonal productions

Membership functions (MFs) of zonal productions as a typical case as shown in Figure.4. Here, low and high fuzzy sets have been assigned trapezoidal shape, whereas the medium fuzzy set is assigned triangular shape based on the output of cluster analysis.

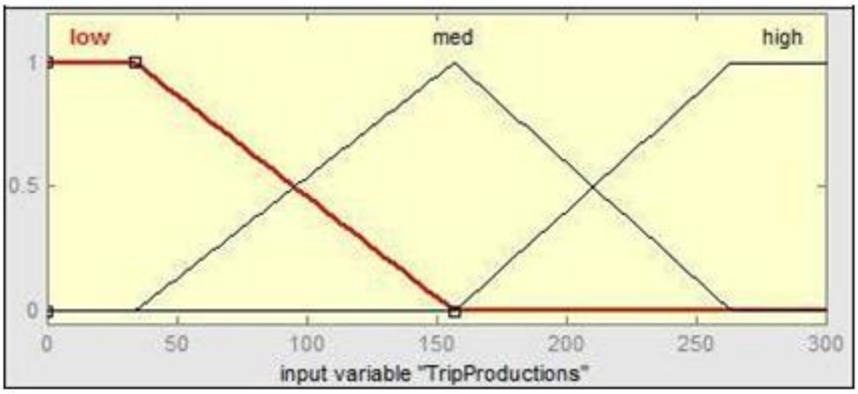

Figure 4: Membership functions for zonal production

Similarly, membership functions of all the input and output variables are obtained using fuzzy C-mean clustering. The details of the MFs of all the variables are given in Table.6.

Table 6: Details of MFs of variables used in FRB-UTDM

Variable	No.of MFs	Linguistic variable	Type of MF	MF Parameters
Total Zonal Productions	3	Low	Trapezoid	[0 0 34 157]
		Medium	Triangular	[34 157 264]
		High	Trapezoid	[157 264 300 300]
Total Zonal Attractions	3	Low	Trapezoid	[0 0 74 121]
		Medium	Triangular	[74 121 364]
		High	Trapezoid	[121 364 400 400]
Distance	3	Low	Trapezoid	[0 0 1.41 3.22]
		Medium	Triangular	[1.3 3.22 6.1]
		High	Trapezoid	[3.22 6.1 7 7]
Trip interchanges	5	Very low	Triangular	[0 0 7 27]
		Low	Triangular	[7 26 43]
		Medium	Triangular	[27 43 56]
		High	Triangular	[35 56 203]
		Very high	Trapezoid	[59 203 250 250]

7.3. Fuzzy Inference System

Mamdani fuzzy inference system consisting of three input variables and one output variables is created. Productions, attractions and distance between the sub-zones are bifurcated into three MFs and are named as low, medium and high. The output variable trip interchanges is divided into five MFs and are very low, low, medium, high and very high as discussed earlier.

7.3.1. Fuzzy Rule-Base Formulation

Fuzzy inference mechanism works on the principle of simple and logical If-then rules. Total 27 numbers of “IF-THEN” rules are formulated here based on the logical thinking and general experience. A typical set of rules can be as follows:

IF<zonal productions are high> AND <attractions are high> AND <accessibility is less>, THEN <the number of trip interchanges are very high>.

7.4. Defuzzification process

The fuzzy output of the fuzzy inference system cannot be used directly for application purpose and hence the defuzzification of the aggregated output fuzzy sets is carried by using Centroid method, to convert the linguistic output into crisp format. The rule viewer can be used as diagnostic to see, the rules which are getting fired for particular input values and how individual membership function shapes influence the results. Here, the typical output value of trip interchanges (21.1) is for the corresponding values of productions (150 trips), attractions (200 trips) and distances (3.5 km) as shown in Figure 5.

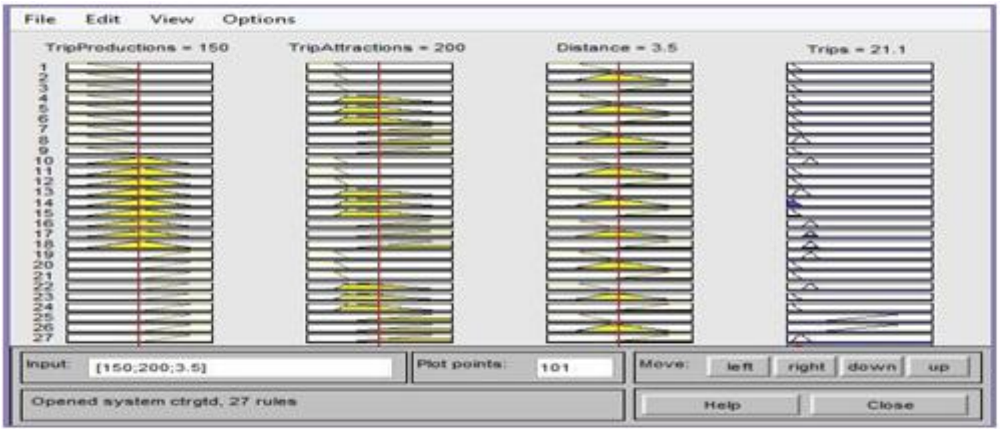

Figure.5. Typical rule viewer window for trip distribution model

7.5. Model testing

The developed FRB-UTDM models for the three income classes were compared with the results of the gravity models for LIG, MIG and HIG. RMSE values were found out for all the models and the comparative table is given below Table.4. FRB-UTDM models have proved better to gravity based trip distribution model with their low RMSE values.

Table.4. RMSE values

Income Categories	**RMSE values**	
	Fuzzy Logic Model	Gravity model
LIG	2.42	2.65
MIG	4.74	5.12
HIG	2.78	3.95

These models are developed based on the sample which is obtained from the survey data, an attempt has been made here to forecast the trips for the entire population of the west zone. Using the expansion ratio, the trip interchanges obtained from the survey data are projected for whole population. Ai/Pi ratio is found out for analyzing the performance of models and the values are given below in the Table 9.

Table.9. Attraction Generation Ratio

Sub zones	**Observed**	**Modelled Ai/Pi**	
	Ai/Pi	Gravity	Fuzzy
Adajan	1.19	1.09	1.06
Rander	0.65	0.67	0.71
Pal	1.15	0.82	1.20
Palanpur	5.99	5.54	5.71

Jahangirpura	0.44	0.57	0.61
Jahangirabad	0.88	1.67	1.21
Chi-Sq Value		0.578	0.171

Lower Chi-square value has been observed for the fuzzy model indicating it as a better operating model than other two models.

VIII. Conclusions

The majority of the trip distribution models developed are based on analytical relations through which the trip interchanges between origin-destination pairs are determined. However, they do not take into account effectively the vagueness of the human mind and the uncertainties associated with trip making. RMSE of the models developed by the soft computing technique FRB are better compared to the conventional Gravity model. Model performance analysis is also being carried out by finding out Ai/Pi ratios for all the three models as discussed, with due consideration of total trips. FRB models have shown better Chi-Squared value compared to the other models clearly indicating that FRB models are superior. From the Chi-Squared values, it is clear that Fuzzy models are superior to Gravity models. It can be inferred that Soft Computing methods like Fuzzy Logic outweighs the conventional Gravity based approach. These approaches can be considered as an alternative to conventional methods. However, it does not mean that conventional Gravity model is to be discarded, as it does not account for the human behavior in urban movement

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