Impact of Proposed Modal Shift from Private Users to Bus Rapid Transit System: An Indian City Case Study

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***Abstract*—**One of the major thrusts of the Bus Rapid Transit System is to reduce the commuter's dependency on private vehicles and increase the shares of public transport to make urban transportation system environmentally sustainable. In this study, commuter mode choice analysis is performed that examines behavioral responses to the proposed Bus Rapid Transit System (BRTS) in Surat, with estimation of the probable shift from private mode to public mode. Further, evaluation of the BRTS scenarios, using Surat's transportation ecological footprint was done. A multi-modal simulation model was developed in Biogeme environment to explicitly consider private users behaviors and non-linear environmental impact. The data of the different factors (variables) and its impact that might cause modal shift of private mode users to proposed BRTS were collected through home-interview survey using revealed and stated preference approach. A multi modal logit model of mode-choice was then calibrated using the collected data and validated using proposed sample. From this study, a set of perception factors, with reliable and predictable data base, to explain the variation in modal shift behaviour and their impact on Surat's ecological environment has been identified. A case study of the proposed BRTS connecting the Surat Industrial Hub to the coastal area is provided to illustrate the approach.

***Keywords*—**BRTS, Private Modes, Mode choice models, Ecological footprint.

I. Introduction

INDIA is failing through an ambitious, globally unique attempt to renew its urban infrastructure and reform the political, institutional and financial relationships between home, province, and city levels of government that have impeded sustainable urban transport development is city [1]. The National Urban Transport Policy (NUTP, 2006) also gives emphasis to ensure safe, affordable, quick, comfortable, reliable and sustainable access to an urban transport system for the growing number of city residents in developing countries [2].

However, today scenario is totally different than the present vision of NUTP. Lack of the urban transportation system fueled high growth of private vehicles in an Indian city. The population of India's six major metropolises increased by about 1.9 times during 1981 to 2001, the number of motor vehicles went up by over 7.75 times during the same period. Cost of travel has increased considerably due to lack of infrastructures for non-motorized vehicles. Non-motorized like cycling and walking modes have to share the same road space with motorized modes, which has become extremely risky due to high rate of fatality. Accident rates have gone up from 0.16 million in 1981 to over 0.39 million in 2001[3]. Inadequate roadway planning is performed to accommodate for buses and non-motorized transport in urban arenas.

Due to the number of over bridges and under bridges are increasing in the city that makes extremely increase the speed of traffic and cause high traffic fatalities, especially among pedestrians, elderly people, Bicyclist and two wheelers. Overcrowded, uncomfortable, undependable, slow, uncoordinated, inefficient, and dangerous public transport system is causing more mode shift towards private vehicles. High speed vehicular stream in urban area causes transport-related pollution, noise and other environmental impacts on human being, which cannot be the sign of sustainable transportation [4].

Along these lines, the objective of the present paper is to contribute to the literature in three ways. First, the analysis of mode shift from private vehicle to proposed BRTS is based on data collected as part of a commuter behavior response survey conducted in the selected corridor of Surat during the winter of 2010. An understanding of the attitudes and behaviors of commuters is a necessary condition to the creation of an effective transportation system intended to encourage more efficient use of urban public transportation [5].

Secondly, this paper outlines an impact of the proposed BRTS model as a model of the sustainable urban transport and demonstrates how mode shift may be used to assess the relative contribution of the urban transportation system to the quality of life of communities while considering their impact on the ecological environment. Using the ecological footprint methodology attempt is made to evaluates different scenarios of urban transportation system and examine their impact on the Surat' ecology. Finally, the analysis helps to uncover the attitudinal variables that impact the commuter by discussing implications of adopting BRTS system in current Indian urban chaos.

II. Study Areas

Surat city is considered as 'now exploding' categories of the city along with Bhopal, Indore, Jaipur, Mysore and Rajkot. Surat city municipal area is 312 Sq km and according to the 2001 census, its population is 2.4 million persons. The projected population growth rate for 2021 of Surat city is more than 150%. At present, typical trip length of Surat city is less than 6 km, however, it is likely to increase due to increase in per capita income and restructuring industrialization. Average

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travel speed is about 20 kmph. Non- motorized transport mode share is about 15% and amazingly walking mode share is about 40%. Public transport and intermediate public transport mode share are less than 3 % and about 11%. Two- wheeler and motorized transport mode share is around 25 to 30 % [6]. The population of Two-wheeler finds more than 450 per 1000 persons.

However, the population of car in Surat is found less than 75 per 1000 persons. The CO_2 emission for Surat is estimated around 0.035 tons per capita per year. The CO_2 emission is likely to increase as people shift from non- motorized to Two-wheeler and Two-wheeler to Car due to economic growth. Seven corridors are proposed to implement Bus Rapid Transit System in Surat as shown in Fig. 1. The selected corridor for study is Dumas resort-canal road-Sarthana- Jakaatnaka road, which is 23.5 km long.

Fig. 1 Proposed Dumas resort-canal road BRTS Corridors of Surat City

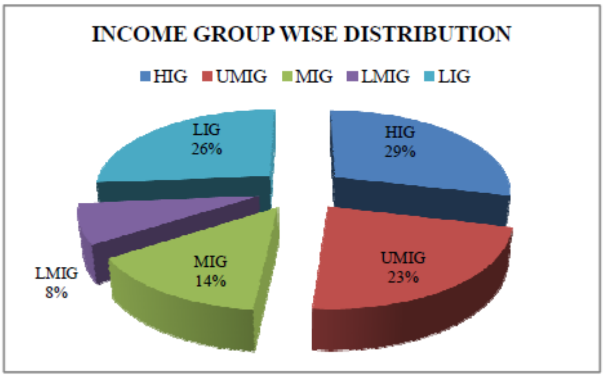

Fig. 2 Income wise distribution of commuters on selected corridor

Selected corridor is located in a typical mixed land use pattern of Surat City. Corridor runs through South to West. West side, the end of the corridor is located near the Arabian Sea. North - South location of the corridor crosses many Industrial and Education Institution.

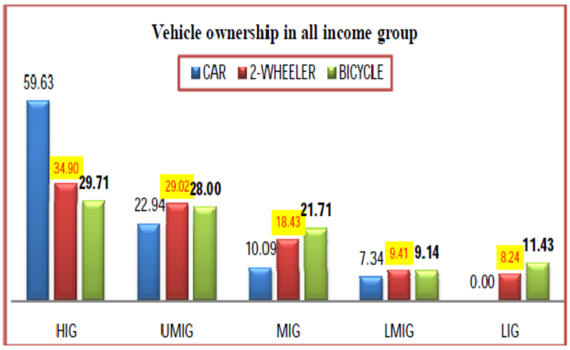

Fig. 3 Vehicle ownership along the selected corridor

The proposed corridor also passes through Interchange from BRTS System to local Bus System and Surat Bus Stand and Railway Station. Therefore, this corridor is strategically very complex with respect to modal shift analysis and impacts on the ecology of Surat. Due to the diverse land use pattern on the 23.5km long corridor, whole commuters who may use this corridor was divided into five income groups as shown in Fig. 2 and their vehicle ownership is shown in Fig. 3. The trip length is measured for compulsory and voluntary trips as shown in Table I. Finally Model split for Compulsory and Voluntary trip is estimated on the proposed BRT corridor.

From the observations of model split data Maximum trip length is in HIG with 22km (Average trip length 5.5km) for which preferable mode is the car. In LIG average trip length is 3.23km for which walk and bicycle trips are more. For compulsory trip maximum share is about two-wheeler whose use is 64% in overall modal split. The second competing mode is Auto-rickshaw with modal share of 50% in voluntary trip. The maximum trip rate is observed in LMIG (1.0 trip per capita per day) for compulsory trips whereas in it is low in LIG (0.82 0 trips per capita per day). Public transport is predominantly in use by the mode captive and students (for compulsory trips). People are concerned about the cost and the punctual service of the public transport service [6].

TABLE I
AVERAGE TRIP LENGTH OF ALL INCOME GROUPS ON THE CORRIDOR

Income Group	Compulsory Trips (km)	Voluntary trips (km)
HIG	5.79	6.29
UMIG	3.85	5.15
MIG	4.62	3.92
LMIG	4.05	3.96
LIG	3.23	4.91

III. METHODOLOGY

The proposed an unbiased disaggregate model and its approximation model was based on the combination of a revealed preference (RP) and stated preference (SP) survey, conducted to study commuter's present travel preferences and their willingness to change to the proposed BRTS. Using an RP and SP approach, a sum of 1250 commuters were interviewed and each individual commuter was presented nine choices sets where he/she had to put forward his or her choice on the different available mode along with different alternative options of the proposed BRTS system during the sketch.

The binary logit analysis was employed to model the attributes and preferences of the commuters through their stated choices. The model was used to derive polynomial linear utility function and an estimation of the relative importance of the proposed BRTS attributes. Modeling of SP and RP was based on the spatial and income differences of the individual commuters and also the data to determine which attributes, including the comfort measure, were significant in predicting the choice of transportation mode. The methodology utilized is outlined in detail in Ben-Akiva and Lerman [7]. Logit models determine the probability that a node will be chosen based on comparison between individual utilities for each mode. The differences between model attributes for each individual are used to determine the choice.

This can be expressed as:

$$\Pr\ (\text{Private to BRTS Mode}) = \frac{e^{U_{BRTS}}}{\sum (e^{U_{BRTS}} + e^{U_{\Pr ivateMode}})} \quad (1)$$

There were two procedure used to estimate these models are Biogeme and SPSS 16. A SP choice of the individual may have longer travel time for all modes compared to another individual. It is only the difference between a given individual’s travel times that determines their choice.

IV. Transport Ecological Footprint

The transportation, ecological footprint is a resource management tool that evaluates how much land and water area a human population needs to get the resources it consumes and to take in its wastes under the prevailing transportation system. The Transport ecological footprint is derived by combining the physical footprint and the energy footprint [8].

$$\text{Total transport ecological footprint} = \text{Physical footprint} + \text{Energy footprint} \quad (2)$$

where, physical footprint means Total road area = Total road length ×Average road width and Energy footprint means energy consumed in one year and the resulting carbon dioxide emission emitted from the vehicles traveling along the road network. It also includes the energy spent and the resulting emissions, on the construction and the maintenance of the roadway network, allocated over the life of the network. This emission figures are then converted to land area measured in hectare by the use of carbon sequestration factor giving the amount of forest land required to sequester all the emissions consumed in the operation of the transport network.

V. Model Inputs

Based on SP questionnaire prepared, home- interview survey was carried out in the residential area on the proposed Jataknaka- Dumas BRTS corridor. As the commuters state their preference after perceiving the cost of travel, comfort during travel and time of travel etc. The variables entered in the model are the proposed BRTS attributes and current travel choice attributes as given in Table II. However, for modeling in Biogeme, only travel cost, travel time, travel distance (combined used for compulsory and voluntary) and average Income was considered.

TABLE II
Definition of Inputs Variables

Variable name	Description
Income Group (IG_1)	People in High Income Group (>Rs.20000)
Income Group (IG_2)	People in Medium Income Group (> Rs. 12000)
Income Group (IG_3)	People in Medium Income Group (< Rs.12000)
Gender (G)	Male (0) /Female (1)
Trip Length (TL)	Access walk distance plus in-vehicle traveled distance
Trip Frequency (TFC)	Average daily compulsory trip
Trip Frequency (TFV)	Average daily voluntary trip
Travel Time (TT)	Total travel time i.e. walk time plus in-vehicle time
Travel Cost (TC)	Out of pocket cost for one travel trip

VI. Model Calibration

As discussed in data input section, Independent variables are discrete in nature; the model was estimated by maximum likelihood estimation. The home-interview survey was conducted with each 250 vehicle users. There were five modes was considered, namely Car, 2-W, Shared Auto, Local Bus and Bicycle. The five data sets pertaining to the 250 each for five modes users, with their willingness for shifting from their respective mode to BRTS was processed into 1250 data points for modeling. The 75% observation was used for the purpose of model calibration and rest of data was used for model validation. The Maximum Likelihood estimation for 2-wheeler mode and model calibration was done using SPSS (version 16) and Biogeme (version 3.4) and results are shown in Tables III-IV.

All attributes and the constant term have a t- statistic greater than 1.96 (more than 95% confidence). Overall the model has a likelihood ratio-Index ρ^2(pseudo-R^2) of 0.358 when comparing the log likelihood at Zero and the log likelihood at convergence which indicates a good model fit.

TABLE III
Model Calibration Results in SPSS Environment

Independent Variables	Parameters estimated	t-test	p- value
IG_1	0.177	25.68	0.00
IG_2	0.185	23.68	0.00
IG_3	1.548	26.24	0.00
G	0.065	23.67	0.00
TL	-10.772	- 14.56	0.00
TFC	1.078	18.68	0.00
TFV	-0.1	-1.88	0.00
TT	-2.0073	-12.34	0.00
TC	- 0.0215	-5.16	0.00
Constant	- 2.807	-8.65	0.00
Likelihood ratio index ρ^2	0.358		

TABLE IV
MODEL CALIBRATION RESULTS IN BIOGEME ENVIRONMENT

Independent Variables	Parameters estimated	t-test	p- value
IG	0.00567	1.78	0.00
TL	-5.675	- 5.97	0.05
TT	-0.92	- 4.68	0.00
TC	- 0.11	- 1.93	0.01
ASC	- 0.807	- 1.68	0.19
Likelihood ratio index ρ^2	0.164		

All attributes and the constant term have a t- statistic greater than 1.96 (more than 95% confidence). Overall the model has a likelihood ratio-Index ρ^2(pseudo-R^2) of 0.358 when comparing the log likelihood at Zero and the log likelihood at convergence which indicates a good model fit. As shown in Table III, t-statistic for different variables compared with corresponding table value, shows that all the parameters estimated are significant at 1% level. Overall the model receives a likelihood ratio-Index ρ^2(pseudo-R^2) of 0.164 when comparing the log likelihood at Zero and the log likelihood at convergence, which is nearly lower than the acceptable range (0.2 - 0.4). This indicates a fairly good model fit. Model estimation carried out by assuming that there are five available traffic modes from an origin to a destination, the utility function of each individual for each traffic mode will be generated. For example, the constant of 2-wheeler, utility function is given in (3). Further, same constants will also be used for BRTS as given below for SPSS and Biogeme environment respectively.

$$U_m = -2.807 + (0.177\times IG_1) + (0.185\times IG_2) + (1.548\times IG_3) + (0.065\times G) + (-10.772 \times TL) + (1.078\times TFC) + (-0.1\times TFV) + (-2.0073\times TT) + (-0.0215\times TC) \quad (3)$$

Um = ASC + (TT * Travel Time) + (TC *Travel Cost) + (IG * Income) + (TL* Distance)

VII. MODEL VALIDATION

The proposed model was validated with 25 % data point of five data sets. This was done in SPSS and Biogeme environment using objective maximize the utility of particular modes as an explanatory factor in addition to other variables. In order to determine the modal shift by another procedure, was also employed to find out explanatory variable factors for the above mentioned 2-wheeler mode and BRTS. With 25% observations, Log-likelihood was estimated. Calibrated model (using 75%) was used to predict the modal shift, and the value of Log-likelihood calculated. Then, Log-likelihood was compared to their closeness as shown in Table V.

TABLE V
VALIDATION RESULTS FOR THE MODEL

Description	Initially calibrated with 75% data	Calibrated with 25% data
Null Log-likelihood	-422.177	-188.536
Initial Log-likelihood	-422.177	-188.536
Final Initial Log-likelihood	-352.817	-153.549
Likelihood ratio test	138.618	69.975
Likelihood ratio index ρ^2	0.164	0.186

It can be seen from Table V that two Log-likelihood values are fairly close to each other, thus proving the validity of the model. Hence, the validation result may be considered to be fairly satisfactory.

VIII. RESULTS AND DISCUSSION

A. *Description of Utility Shift from Two-Wheeler to BRTS*

Travel time, Travel cost and Trip Length have negative coefficients which suggest that the utility of an alternative decreases as the values of these terms increases. The value of the travel cost is varying as per the income group of the respondent which shows that higher income group has less value on cost as compared to lower income groups. As per the income groups, higher income groups are less likely to use Two-wheeler as suggested by the less positive coefficient. SPSS and Biogeme model shows a shift of 37.38% and 45.46% from 2-wheeler to BRTS respectively. The Likelihood ratio index (ρ^2) value 0.164 suggests that it is representing a fairly good model.

B. *Description of Utility Shift from Shared Auto to BRTS*

Travel time, Travel cost and Trip Length have negative coefficients which suggest that the utility of an alternative decreases as the values of these terms increases. As per the income groups, higher income groups are less likely to use Shared Auto as suggested by the negative coefficients. SPSS and Biogeme model shows a remarkable shift of 80.58% and 87.40% from Shared Auto to BRTS respectively.

C. *Description of Utility Shift from Car to BRTS*

Travel time, Travel cost Trip Frequency and Trip Length have negative coefficients which suggest that the utility of an alternative decreases as the values of these terms increases. As per the income groups, higher income groups are more likely to use Cars as suggested by the higher positive coefficients. SPSS and Biogeme model shows a shift of 6.78% and 11.49% from Cars to BRTS respectively.

D. *Description of Utility Shift from SMC Bus to BRTS*

Travel time, Travel cost and Trip Frequency have negative coefficients which suggest that the usefulness of an option decreases as the values of these terms increases. As per the income groups, with the increase in income, the commuters are less likely to use the mode as suggested by the negative coefficients. SPSS and Biogeme model shows a significant shift of 71.99% and 85.16% from the SMC Bus to BRTS respectively.

E. *Description of Utility Shift from Bicycle to BRTS*

Travel time, Travel costs, Trip Length and Trip Frequency have negative coefficients which suggest that the utility of an alternative decreases as the values of these terms increases. As per the income groups, the commuters with lower income are more susceptible to use Bicycle as suggested by higher positive coefficients. SPSS and Biogeme model shows a significant shift of 55.87% and 64.91% from Bicycle to BRTS respectively.

F. Total Ecological Footprint

The total Transport ecological footprint is derived by blending the physical footprint and the energy footprint. Physical footprint is the surface area of the roadway paving. It remains unchanged in both the scenarios, prior to BRTS and after BRTS whereas, the Energy Footprint is the annual emission of CO_2 (hectare). The Total Energy Footprint after the implementation of BRTS project reduces of 2.57% as compared to the present scenario before the implementation of BRTS in the corridor level of 23.5km.

IX. Conclusions

The following are the important findings of the study:

(1) Through this study, a set of factors with reliable and predictable data base such as Income Groups, Gender, Trip Length, Trip Frequency, Travel Time and Travel Cost, has been identified that explains the variation in modal shift behavior of various modes to BRTS.

(2) The calibrated Multinomial Logit model of modal shift (involving all trips and all variables) is found to be statistically significant with a satisfactory rho-square value. The model, when validated using hold-out sample, was found to be valid based on the comparison of the predicted LL value against the originally estimated LL value.

(3) Analyzed data shows about 42.1% and 49.07% of the commuters is willing to shift to BRTS based on SPSS and Biogeme analysis respectively. When analyzing current mode, it reveals that Shared Auto and SMC bus users respectively are more likely to use the BRTS with 84% and 78.575% willingness of modal shift respectively.

(4) Ecological footprint analysis scenario with two comparative cases shows very significant change in environmental sustainability. With BRT and without BRT case in transportation environment will make 2.5618 % reduction in the Total Energy Footprint at corridor level.

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