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Modelling Modal Shift from Personal Vehicles to Bus on Introduction of Bus Priority Measure

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Abstract: This study is concerned with estimation of the probable shift of personal vehicle users to bus due to the increase in its level of service as a result of the provision of exclusive bus lanes on Indian city roads. The quantum of increase in level of service of bus due to introduction of exclusive bus lanes was determined using a recently developed simulation model for heterogeneous traffic flow. The data on the other factors (variables) that might cause modal shift from personal vehicles to bus were collected through home-interview survey using a stated preference approach. Mode-choice models to explain the shift behaviour of the users of motorised two-wheelers, auto-rickshaws, and cars to buses are developed. Modal shift probability curves are also developed to serve as a user friendly tool to analyze the probable modal shift for a wide range of the variables.

Keywords: *Heterogeneous traffic flow, Exclusive bus lane, Stated preference approach, Modal-shift probability curve*

1. INTRODUCTION

Bus is the main urban transit system used in most Indian cities and gradually, its level of service is declining due to inadequate capacity and managerial and financial problems. In the absence of an adequate and efficient bus transit system, the potential bus users currently use personal transport modes - mainly motorized two-wheelers and, to some extent, cars. Also, some of them resort to the use of a para-transit mode called auto-rickshaw (three-wheeled motorized vehicle to carry passengers based on fare rates), which is very popular and is a common mode of transport in many Asian cities. Thus, a large number of private and para-transit vehicles have entered into the market to meet the travel demand. As the available road space is limited, the proliferation of these vehicles results in severe congestion, inordinate delay, higher fuel consumption, (particularly of fossil fuels) and intense pollution. Indian cities desperately need improved and expanded public transport service and not personal vehicles. This requires both an increase in quantity as well as quality of bus transport services and effective application of demand management as well as supply-side management measures. One way of achieving this goal is provision of reserved bus lanes on major urban roads. Provision of exclusive road space, thus, will enhance the level of service of buses and this may also result in a shift of some of the personal vehicle users to buses. This study is intended to estimate the probable shift of personal vehicle users to buses using an appropriate mode-choice modelling technique as assessment of the impact of the provision of exclusive bus lanes on roads carrying highly heterogeneous traffic flow.

2. REVIEW OF EARLIER STUDIES

As this study pertains to the analysis of modal shift from personal vehicle to bus, the review of literature presented here is confined to the research works related to the choice behaviour of travelers, under conditions wherein one of the involved modes is bus. Tischer and Dobson (1979) studied the factors which influence the intentions of the single-occupant commuters to switch to buses and carpools and suggested operating policies consistent with the intent to encourage the use of high-occupancy vehicles. They found that in buses, convenience is the most important variable associated with the intention to shift. They also found that perceptions of carpool comfort do not appear to be important, rather, perceptions of carpool schedule flexibility, cost, safety and a short wait in traffic were found to be the prime factors associated with potential shift to carpool. Mackett (2003) identified different policy actions to reduce car use for different types of trips and the actions that are required to meet the travel needs that the car currently fulfills. The evidence on why people used their cars for a set of real short trips is considered in terms of a number of dimensions including age, sex, and trip purpose. This is followed by a discussion of the alternative modes to the car that drivers say that they might adopt and the factors that would make them consider switching to these alternatives. The analysis of results from the surveys shows that “Improving public transport” is the specific action, which drivers say, is most likely to attract them out of their cars. Alvinsyah *et al.* (2005) developed a binomial logit model based on Stated Preference (SP) data to study the response of the travelers in using the proposed Jakarta busway system. Travel time and travel cost were considered as the main variables to develop utility functions. Based on these modal characteristics and the different service strategies offered, people’s perception and their probability of selecting the proposed system is predicted. The results show a wide range of people’s perception and their probability of choosing the better service. Nurdden *et al.* (2007) identified the factors that prevent personal transport users from utilizing public transport so that rational polices could be formulated to encourage greater utilization of public transport. Binary logit models were developed involving car and bus, & car and train. The most important variables, found likely to encourage the use of public transport, were reduced travel time, walking distance to public transport stations and subsidized fare. Gebeyehu and Takano (2007) studied the citizens’ perceptions of the bus condition as a determining factor for their choice of bus transportation, and developed a binary logit model to analyze traveler choice behavior. The result of the study shows that citizens’ perceptions of the three chosen bus-transit condition attributes (fare, convenience, and frequency) have a significant influence on public-transport-mode choice. All these studies, in summary, are motivating and shed some light on the factors that influence the way individuals decide on their modes of travel and the contrasting roles of perceptions and satisfactions in their ability to respond to switching intentions to buses. At present, there is no research available in behavioral study of switching intention of personal vehicle users to buses under traffic conditions prevailing in developing countries like India. This study is therefore an attempt to fulfill this need.

3. METHODOLOGY

Based on the literature, two different approaches are used in modal shift analysis: Revealed Preference (RP) approach and Stated Preference (SP) approach. The RP approach has been used to model mode-choice when data on actual choice of mode by travellers are available. Whereas, the SP approach has been used to analyze the response of people to hypothetical choice situations. These, of course, can cover a wider range of attributes and conditions than the real system. In the present study, an SP approach has been adopted for the model development. The aim here is to examine how modal shift characteristics vary across different personal vehicle (motorized two-wheeler, car and auto-rickshaw) users and to estimate the probability of shift from each personal vehicle to bus by treating each type of personal vehicle independently. Thus, the modes considered for modelling were only bus and any one personal vehicle (at a time). Hence, a binary choice model was used for the modal shift analysis. As the interpretation and specification are straightforward in the logit model in contrast to the probit model, the logit model was adopted in the analysis.

4. MODEL SPECIFICATION

The model specification here is based on utility theory, which is based on the assumption that individuals select that mode which maximizes their utility (*U*). Utility theory enables prediction of changes in choices that occur when an attribute of one of the alternatives changes. Moreover, the utility based model is able to capture differences in the responses of different individuals to the same attribute change. The utility of an alternative *i* is assumed to be made up of two terms: a deterministic term (V) representing systematic and observed effects and a random term (ε) representing unobserved factors affecting the choice. The random-error term ε, is assumed to be independently and identically distributed following a Gumbel distribution. As per this theory, an individual is likely to shift from a personal vehicle to bus if the utility of bus mode is more than the utility of personal vehicle (e.g. car). Without loss of generality, it can be said that the utility of shift is given as the difference between utilities of bus and car. Therefore, a traveller is likely to shift from car to bus if the utility difference, $U_{diff.} \geq 0$. The utility of shifting is also assumed to be made up of two terms: a deterministic term ($V_{diff.} = V_{Bus} - V_{Car}$) representing systematic and observed effects and a random term ($\varepsilon_{diff.} = \varepsilon_{Bus} - \varepsilon_{Car}$) representing unobserved factors affecting choice. Based on the said assumptions, it can be shown that $\varepsilon_{diff.}$ is distributed as per the logistic distribution. Therefore, the probability of shift is given below.

$$P_{shift} = Pr(U_{diff.} \geq 0) = Pr(V_{diff.} + \varepsilon_{diff.} \geq 0) = \frac{e^{V_{diff.}}}{1+e^{V_{diff.}}} \geq 0 \quad (1)$$

The deterministic term V_{diff} is assumed to be given by a linear-in-parameters specification.

$$V_{diff.} = A_0 + A_1X_1 + \ldots\ldots + A_nX_n \quad (2)$$

Therefore, the probability of shift (given by equation (1)) can be given as,

$$P_{shift} = \frac{e^{V_{diff.}}}{1+e^{V_{diff.}}} = \frac{e^{A_0+A_1X_1+A_2X_2+\ldots\ldots+A_nX_n}}{1+e^{A_0+A_1X_1+A_2X_2+\ldots\ldots+A_nX_n}} \quad (3)$$

where, P_{shift} : Probability of shift from car to bus mode
$V_{diff.}$: Deterministic utility function of difference in utilities of bus and car
$A_0, A_1, A_2\ldots$: the model parameters to be estimated
$X_1, X_2\ldots$: the variables influencing modal shift.

5. DATA BASE FOR STATED PREFERENCE SURVEY

As the objective here is to predict the aggregate shift of personal vehicle users to bus, consequent on reduction in travel time of buses due to provision of exclusive bus lanes, it is necessary to estimate the possible reduction in travel time of buses due to provision of exclusive bus lanes under the prevailing roadway and traffic conditions. For this purpose, Chennai city, in the south eastern part of India, was considered as example. The major roads in Chennai city, which carry a significant amount of bus traffic, are either six-lane divided or eight-lane divided roads. Thus, the width of road space available for one-way movement on these roads is equivalent to either three or four lanes, which are sufficient to allocate one lane exclusively for buses. To conduct the stated preference survey, it is necessary to know the speeds of buses and personal vehicles on these two types of roads for a wide range of traffic-volume conditions. This can be achieved through appropriate traffic simulation experiments. As the available simulation models are based on fairly homogeneous traffic conditions where strict lane discipline exists, these models are not suitable for simulating Indian traffic conditions. Hence, a recently developed and validated model of highly heterogeneous traffic flow prevailing on Indian roads (Arasan and Koshy, 2005) was used for this study. For the purpose of this study, a traffic composition representing the mean composition of traffic on the major roads of Chennai city, (Bus-5%, Truck-1%, LCV-3%, Car- 18%, M.Th.W-12%, M.T.W-55% and Bicycle-6%) was considered The roadway widths, for the simulation of traffic flow in one direction, were fixed as 11.0 m (3 lanes) and 14.5 m (4 lanes). The traffic flow on the assumed arterials was simulated for road conditions with and without bus lane for a wide range of traffic volume (from near free flow condition to capacity level).

The journey speed of buses and personal vehicles were obtained through simulation experiments, for the two roadways and a range of traffic volume conditions. As per the recommendations of Indian Roads Congress (IRC 106: 1990), the desirable level of service for urban roads is ‘C’ and the corresponding traffic volume level is equal to about 0.7 times the capacity. Hence, it would be appropriate to consider this value (volume-to-capacity ratio = 0.7) as the base for determining the speed difference between bus and personal vehicles. Accordingly, it was observed that the differences in journey speed (alternatively the differences in in-vehicle travel time), between buses (on exclusive lane) and motorized two-wheelers (speed of bus minus speed of motorised two-wheeler), expressed as the percentage of bus speed, were 4 and 39% for three-lane and four-lane cases respectively. The differences in journey speed between buses and cars were found to be 16 and 48% for three and four-lane cases respectively. Similarly, the differences in journey speed between buses and auto-rickshaw, were found to be 19 and 47 % for three and four-lane cases respectively. These results were used as the base to prepare the questionnaire for the SP survey.

6. STUDY AREA AND SURVEY DESIGN

In order to use a model in a practical situation, it is necessary to estimate the model parameters using survey data. To study the effect of reduction in travel time on the demand for bus travel, a Stated Preference (SP) questionnaire was prepared. The data of the factors (variables) that might cause modal shift from personal vehicle (motorized two-wheeler, car and auto-rickshaw) to bus were collected through home-interview survey, conducted in a residential area, named Todhunter Nagar. This is in the southern part of Chennai city, India, which has reasonable accessibility to bus service (walking time to bus stop varies from 3 to 15 minutes). The home-interview survey was carried out in households owning personal vehicles. During the survey, the respondents were asked to base their responses on their previous-day trips. The questionnaire had provision to collect data on the following attributes: (a) Gender (b) Age (c) Walking time to bus stop (d) Trip purpose and (e) Willingness (or otherwise) to shift to bus for a given set of possible in-vehicle travel time differences (bus travel time being 0, 10, 20, 30 and 40% less than the travel time by personal vehicle). The list of variables considered for modelling and their descriptions are given in Table 1.

Table 1. Description of the variables considered for modelling

Variable name (1)	Description and coding details (2)
Gender	Male/Female. The variable will be assigned value 0, if male and 1, if female.
Age 1	People in the age group, 10-20 years. The variable will be assigned the value 1, if the respondent falls in the age group and zero, otherwise.
Age 2	People in the age group, 21-40 years. The variable will be assigned the value 1, if the respondent falls in the age group and zero, otherwise.
Age 3	People in the age group, 41-60 years. The variable will be assigned the value 1, if the respondent falls in the age group and zero, otherwise.
Age 4	People in the age group greater than 60 years. The variable will be assigned the value 1, if the respondent falls in the age group and zero, otherwise.
Walking time 1	Walking time to bus stop is ≤ 5 minutes. The variable will be assigned the value 1, if the walking time of the respondent falls in this range and zero, otherwise.
Walking time 2	Walking time to bus stop is 6-10 minutes. The variable will be assigned the value 1, if the walking time of the respondent falls in this range and zero, otherwise.
Walking time 3	Walking time to bus stop is greater than 10 minutes. The variable will be assigned the value 1, if the walking time of the respondent falls in this range and zero, otherwise.
Trip-W	Trip made for work. The variable will be assigned the value 1, if the trip under consideration is made for work and zero, otherwise.
Trip-E	Trip made for education. The variable will be assigned the value 1, if the trip under consideration is made for education and zero, otherwise.
Trip-O	Trip made for other purposes. The variable will be assigned the value 1, if the trip under consideration is made for other purpose and zero, otherwise.

To estimate the percentage of personal vehicle users, who are likely to shift to buses due to its increased speed (consequent on exclusive bus lane implementation), three separate binary mode-choice models: (i) shift from motorized two-wheeler to bus, (ii) shift from car to bus, and (iii) shift from auto-rickshaw to bus were developed and the details are given in the following sections.

7. SHIFT OF MOTORIZED TWO-WHEELER USERS TO BUS

7.1 Model Calibration

In this study, the stated preference (willingness to shift) of the respondent is the dependent variable and gender, age, walking time to bus stop, trip purpose and travel time difference are the independent variables considered for model formulation. The model was calibrated by maximum-likelihood estimation using Newton Raphson method. For a fixed set of data and underlying probability model, the maximum-likelihood picks the values of model parameters that make the data "more likely" than any other values of the parameters would make them. For the model-calibration analysis, a software tool, named, Statistical Software Tools (SST) was used.

The data set pertaining to the 150 two-wheeler users, with their responses for shifting to bus for five travel-time-difference scenarios that were obtained through the home-interview survey, was processed into 750 data points (5×150) for modelling. For the purpose of model calibration, a set of 600 data points (80% of the total) was used, while setting aside the rest of the data (20%) for the purpose of validation. The goodness-of-fit for the calibrated model can be assessed by likelihood ratio index (ρ^2) which is given by,

$$\rho^2 = \frac{LL(\mathrm{P}) - LL(0)}{LL(0)} \tag{4}$$

where, LL (P) = Log-Likelihood of the estimated model; LL (0) = Log-Likelihood when the coefficients are assumed to be zero.

The model calibration results are shown in Table 2. It can be seen that, the signs of the parameters of the variables are logical. The values of the t-statistic for the different variables when compared with the corresponding table values, indicate that all the parameter estimates are significant at 5 % level. Also, it may be noted that the other variables related to age (Age 1, Age 2 and Age 4) are found to be insignificant, for the reason that people of these age groups differ significantly (compared to the group pertaining to Age 3) in their willingness to shift to Bus.

Table 2. Results of model calibration

Variable (1)	Parameter estimate (β) (2)	t-statistic (t) (3)
Constant	- 0.66	- 2.44
Gender	0.62	2.23
Age 3	0.67	2.35
Trip-W	0.71	3.03
Walk Time -3	- 0.58	- 1.87
Percent Time Difference	7.09	7.74
Likelihood Ratio Index (ρ^2) = 0.334		

Table value of t, @ 5% level of significance, = 1.64.

7.2 Model Validation

For the purpose of model validation, the holdout data set with 150 data points, was used as follows: First, a separate model of modal shift using the data of the hold out sample was calibrated and the Log-Likelihood (LL) was estimated. Next, the model initially calibrated using the 600 data points was applied to the hold out sample to predict the modal shift and the value of LL was calculated. Then the two values of Log- Likelihood were compared for their closeness. The relevant details are given in Table 3. It can be seen that the two Log-Likelihood values are close to each other, thus proving the validity of the model. The acceptable ρ^2 value ranges from 0.2 to 0.4 (Alvinsyah *et al.*, 2005) and ρ^2 values around 0.4 may give excellent fits (Ortuzar and Willumsen, 2004). Hence, the validation result may be considered to be satisfactory.

Table 3. Results of model validation

Description (1)	Value of model statistics (2)	
	Model initially calibrated with 600 data points	Model calibrated using the hold-out sample with 150 data points
Initial LL	-415.89	- 103.97
Final LL	-275.96	- 69.46
ρ^2	**0.334**	**0.331**
Estimated LL		- 69.46
Calculated LL		- 63.06

7.3 Sub Model Considering Only Travel-Time Difference

For policy decisions on urban transport demand management, it would be appropriate to consider the impact of changes in the operating characteristics of travel mode(s). Accordingly, in this case, it would be appropriate to estimate the probability of shift to bus considering only travel time as the influencing variable. Accordingly, the model of modal shift for trips made for all purposes as well as for the purpose of work, education and others, were calibrated and validated by considering travel time difference as the only basis for modal shift. The calibration and validation results are given in Table 4. The calibrated models were then used to predict the aggregate shift of two-wheeler users to bus, the only criterion considered being reduction in travel-time by bus. The probability of shift for different travel time differences between motorised two-wheeler and bus, obtained using the calibrated models, are presented in Table 5.

7.4 Modal Shift Probability Curve

To illustrate the usefulness of the modal shift modelling exercise in urban road transport management, the developed aggregate modal shift model, (involving the total trips made for all the different purposes) considering travel-time difference as the influencing variable, was used to develop a modal shift probability curve (Figure 1).

The percentage travel-time difference between bus (on exclusive lane) and motorized-two-wheeler at level of service C, as mentioned in Section 5, are 4 and 39 respectively for the roads with 14.5 and 11.0 m widths. The probability of shifts, then, can be obtained from the curve, as 0.92 and 0.58 for 11m and 14.5m wide road spaces respectively as shown in Figure 1. This implies that about 92% and 58% of Two-wheeler users will shift to bus in the case of 11m and 14.5m wide roads, respectively.

Table 4. Calibration and validation results of the models with travel-time difference as the only causal variable

Influencing variable (1)	Values of parameter and t-statistic							
	All purposes (2)		Work trips (3)		Education trips (4)		Other trips (5)	
	β	t	β	t	β	t	β	t
Constant	0.11	0.72	- 0.18	- 0.94	- 1.21	- 3.39	- 0.52	- 1.55
Time difference*	6.46	7.84	8.09	6.93	5.20	3.32	7.03	4.67
ρ^2	0.30		0.32		0.22		0.25	
Model validation								
ρ^2 (holdout sample)	0.30		0.30		0.20		0.22	
Estimated LL	- 72.89		- 39.24		- 11.38		- 27.726	
Calculated LL	- 63.58		- 36.81		- 13.59		- 21.5	

*Percentage by which Bus journey time is less than Two-Wheeler journey time.

Table 5. Probability of shift of two-wheeler users to bus estimated by taking travel-time difference as the only causal variable

Percentage difference between bus journey time and two-wheeler journey time (1)	Probability of shift (considering the trips made for all the purposes) (2)	Probability of shift (based on trip purpose)		
		Work (3)	Education (4)	Others (5)
0	0.53	0.46	0.23	0.37
10	0.68	0.65	0.34	0.55
20	0.80	0.81	0.46	0.71
30	0.89	0.90	0.59	0.83
40	0.94	0.96	0.71	0.91

8. SHIFT OF CAR USERS TO BUS

This section is intended to describe the estimation process of the probable shift of the car users to buses using binary mode-choice modelling technique, to assess the impact to modal shift of providing exclusive bus lanes.

8.1 Model Calibration

The data set pertaining to the 100 car users including their responses for shifting to bus (for five travel-time-difference scenarios) that were obtained through home-interview survey, was processed into 500 data points (5×100) for modelling. For the purpose of model calibration, a set of 400 data points (80% of the total) was used, while setting aside the rest of the data (20%) for the purpose of validation. The model-calibration results are shown in Table 6. It can be seen that the signs of the parameters of the variables are logical. The values of the t-statistic for the different variables, when compared with the corresponding table values, indicate that all the parameter estimates are significant at 1 % level.

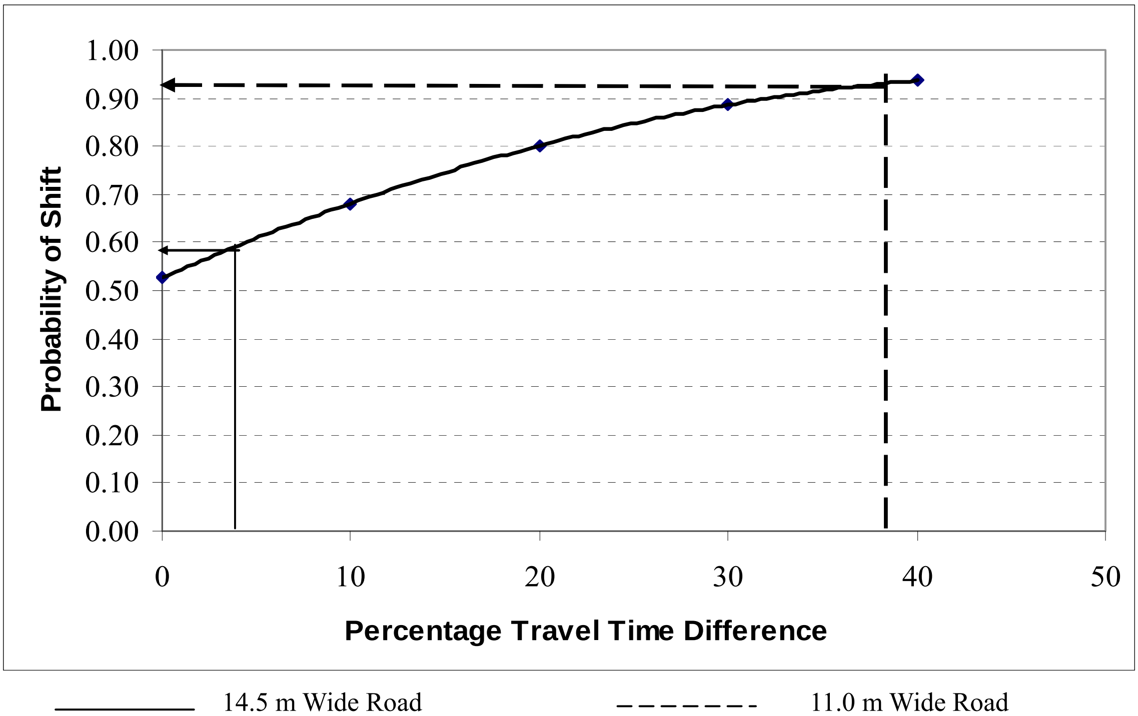


Figure 1. Modal shift probability curve for motorised two-wheeler users

Table 6. Results of model calibration

Variable (1)	Parameter estimate (β) (2)	t-statistic (t) (3)
Constant	- 2.28	- 6.75
Age 3	0.86	3.28
Trip-W	0.63	2.35
Walk time -3	- 1.07	- 2.48
Percentage time difference	6.34	6.15
Likelihood ratio index (ρ^2) = 0.25		

Table value of t, @ 1% level of significance, = 2.33.

8.2 Model Validation

For the purpose of model validation, the holdout data set, with 100 data points, was used as follows: First, a separate model of modal shift, using the data of the hold out sample, was calibrated and the Log-Likelihood (LL) was estimated. Next, the model (initially calibrated using the 400 data points), was applied to the hold out sample with (100 data points), to predict the modal shift and the value of Log-Likelihood was calculated. The two values of Log- Likelihood were then compared for their closeness. The relevant details are given in Table 7. It can be seen that the two Log-Likelihood values are close to each other, thus proving the validity of the model.

Table 7. Results of model validation

Description	Value of model statistics	
	Model initially calibrated with 400 data points	Model calibrated using hold out sample with 100 data points
(1)	(2)	(3)
Initial LL	- 221.81	- 55.45
Final LL	- 165.59	- 41.32
ρ^2	0.25	0.25
Estimated LL		- 41.32
Calculated LL		- 44.06

8.3 Sub Model Considering Only Travel-time Difference

For policy decisions on urban-transport-system management, it would be appropriate to consider the impact of changes in the operating characteristics of travel mode(s). Accordingly, in this case, it would be appropriate to estimate the probability of shift to bus, considering only travel-time as the influencing variable. Accordingly, the model of modal shift for trips made for all purposes as well as for the purpose of work and others (the number of trips made for education, using car, were found to be too small to build a model), were calibrated and validated by considering travel time difference as the only basis for modal shift. The calibration and validation results are given in Table 8. The calibrated models were then used to predict the aggregate shift of car users to bus, the only criterion considered being reduction in travel time. The probability of shift for different travel-time differences between car and bus, obtained using the calibrated models, are presented in Table 9.

Table 8. Calibration and validation results of the models with travel-time difference as the only causal variable

Influencing variable	Values of parameter and t-statistic					
	All purposes (2)		Work trips (3)		Other trips (4)	
(1)	β	t	β	t	β	t
Constant	- 1.90	- 7.59	- 0.88	- 2.95	- 2.06	- 4.81
Time difference*	5.72	6.00	5.62	4.39	5.99	3.94
(ρ^2)	0.22		0.24		0.25	
Model validation						
ρ^2 (holdout sample)	0.23		0.24		0.26	
Estimated LL	- 42.539		- 24.83		- 20.05	
Calculated LL	- 44.60		- 23.48		- 23.44	

*Percentage by which Bus journey time is less than Car journey time

8.4 Modal Shift Probability Curve

To illustrate the usefulness of the modal shift modelling exercise in urban road transport management, the developed aggregate modal shift model, (involving the total trips made for all the different purposes), considering travel-time difference as the influencing variable, was used to develop a modal shift probability curve (Figure 2). The percentage travel-time differences between bus (on exclusive lane) and car at level of service C, as mentioned in Section 5, are 16% and 48% respectively for the roads with 14.5 and 11.0 m widths. The probability of shift, then, can be obtained from the curve, as 0.70 and 0.28 for 11m and 14.5m wide road spaces respectively. This implies that about 70% and 28% of car users will shift to bus in the case of 11m and 14.5m wide roads, respectively.

Table 9. Probability of shift of car users to bus estimated by taking travel time difference as the only causal variable

Percentage difference between bus journey time and car journey time (1)	Probability of shift (Considering the trips made for all the purposes) (2)	Probability of shift (based on trip purpose)	
		Work (3)	Others (4)
0	0.13	0.29	0.11
10	0.21	0.42	0.19
20	0.32	0.56	0.29
30	0.45	0.69	0.43
40	0.59	0.79	0.57

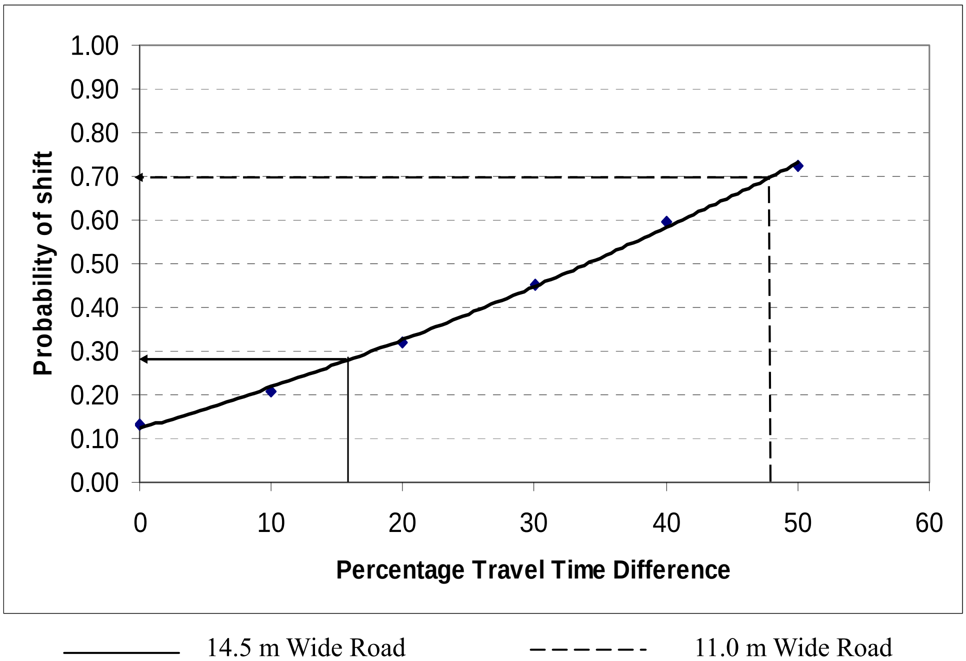


Figure 2. Modal shift probability curves for car users

9. SHIFT OF AUTO-RICKSHAW USERS TO BUS

This section is intended to describe the estimation of the probable shift of the users of the para-transit mode, auto-rickshaw (three wheeled motorised vehicle to carry passengers based on fare rate) to buses using binary mode-choice modeling technique. This is to assess the impact on modal shift of providing exclusive bus lanes.

9.1 Model Calibration

The data set pertaining to the 100 auto-rickshaw users, with their responses for shifting to bus (for five travel-time-difference scenarios) which were obtained through home-interview survey, was processed into 500 data points (5×100) for modelling. For the purpose of model calibration, a set of 400 data points (80% of the total) was used, while setting aside the rest of the data (20%) for the purpose of validation. The model-calibration results are shown in Table 10. It can be seen that, the signs of the parameters of the variables are logical. The values of the t-statistic for the different variables, when compared with the corresponding table values, indicate that all the parameter estimates are significant at 2.5 % level.

Table 10. Results of model calibration

Variable (1)	Parameter estimate (β) (2)	t –statistic (t) (3)
Constant	- 1.87	- 4.52
Gender	1.30	4.44
Trip-O	1.36	3.94
Walk time -3	- 0.88	- 2.23
Percent time difference	8.39	6.74
Likelihood ratio index (ρ^2) = 0.43		

Table value of t, @ 2.5% level of significance, = 1.96

9.2 Model Validation

For the purpose of model validation, the holdout data set with 100 data points was used as follows: First, a separate model of modal shift, using the data of the hold out sample, was calibrated and the Log-Likelihood (LL) was estimated. Next, the model, initially calibrated using the 400 data points, was applied to the hold out sample (with 100 data points) to predict the modal shift and the value of Log-Likelihood was calculated. The two values of Log-Likelihood were then compared for their closeness. The relevant details are given in Table 11. It can be seen that the two Log-Likelihood values are close to each other, thus proving the validity of the model.

9.3 Sub Model Considering Only Travel-Time Difference

For policy decisions on urban transport system management, it would be appropriate to consider the impact of changes in the operating characteristics of travel mode(s). Accordingly, in this case, it would be appropriate to estimate the probability of shift to bus, considering only travel time as the influencing variable. Accordingly, the model of modal shift for trips made for all purposes as well as for the purposes of work and others (the number of trips made for education, using auto-rickshaw, were found to be too small to build a model) were calibrated and validated by considering travel-time difference as the only basis for modal shift. The calibration and validation results are given in Table 12. Then, the calibrated models were used to predict the aggregate shift of auto-rickshaw users to bus, the only criterion considered being reduction in travel time. The probability of shift for different travel-time differences between auto-rickshaw and bus, obtained using the calibrated models, are presented in Table 13.

Table 11. Results of model validation

Description (1)	Value of model statistics: Model initially calibrated with 400 data points (2)	Value of model statistics: Model calibrated using hold out sample with 100 data points (3)
Initial LL	- 276.57	- 70.01
Final LL	- 158.47	- 39.76
ρ^2	0.43	0.43
Estimated LL		- 39.76
Calculated LL		- 34.54

Table 12. Calibration and validation results of the models with travel-time difference as the only causal variable

Influencing Variable (1)	Values of parameter and t-statistic					
	All purposes (2)		work trips (3)		other trips (4)	
	β	t	β	t	β	t
Constant	- 0.18	- 0.97	- 0.47	- 1.31	0.54	3.18
Time difference*	6.09	7.02	8.15	3.65	4.55	3.82
ρ^2	0.27		0.24		0.36	
Model Validation						
ρ^2 (holdout sample)	0.27		0.23		0.37	
Estimated LL	- 51.37		- 13.79		- 33.43	
Calculated LL	- 44.28		- 12.46		- 40.38	

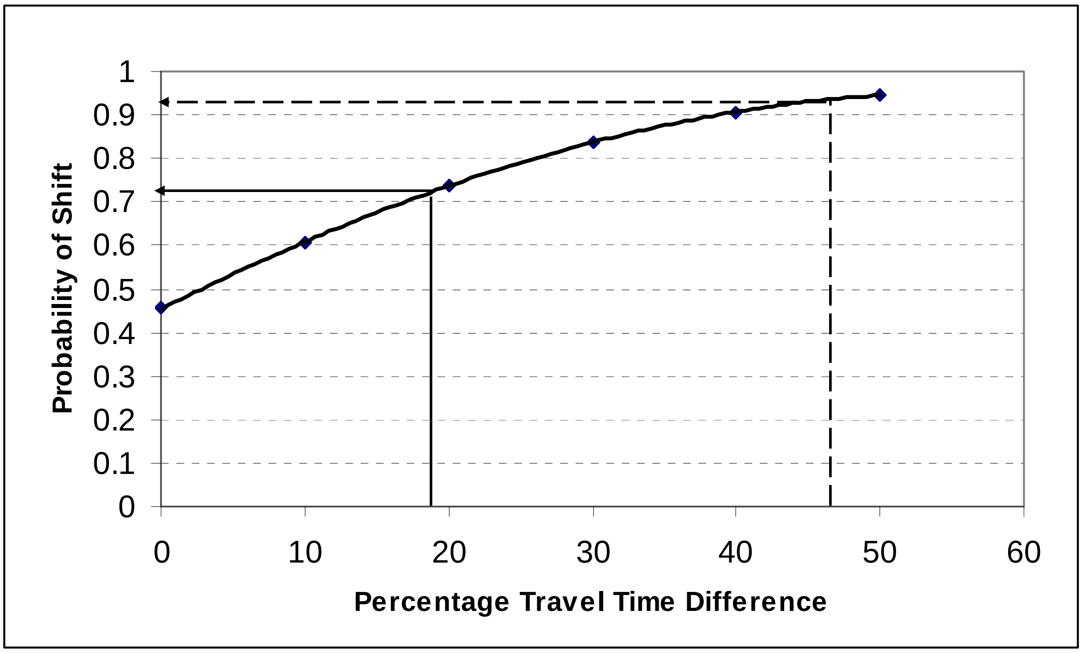
*Percentage by which Bus journey time is less than Auto-rickshaw journey time

Table 13. Probability of shift of auto-rickshaw users to bus estimated by taking travel-time difference as the only causal variable

Percentage difference between bus journey time and auto-rickshaw journey time (1)	Probability of shift (considering the trips made for all purposes) (2)	Probability of shift (based on trip purpose): Work (3)	Probability of shift (based on trip purpose): Others (4)
0	0.46	0.38	0.63
10	0.61	0.59	0.73
20	0.74	0.76	0.81
30	0.84	0.88	0.87
40	0.91	0.94	0.91

9.4 Modal Shift Probability Curve

To illustrate the usefulness of the modal shift modelling exercise in urban road transport management, the developed aggregate modal shift model, (involving the total trips made for all the different purposes) considering travel-time difference as the influencing variable, was used to develop a modal shift probability curve (Figure 3). The percentage travel-time differences between bus (on exclusive lane) and auto-rickshaw at level of service C, as mentioned in section 5, are 19% and 47% respectively for the roads with 14.5 and 11.0 m widths. The probability of shifts then can be obtained from the curve, as 0.92 and 0.72 for 11.0m and 14.5m wide road spaces respectively. This implies that about 92% and 72% of auto-rickshaw users will shift to bus in the case of 11m and 14.5m wide roads, respectively.



——— 14.5 m Wide Road ------ 11.0 m Wide Road

Figure 3. Modal shift probability curves for auto-rickshaw users

10. CONCLUSIONS

Through this study, a set of causal factors with reliable and predictable data base, to explain the variation in shift behaviour of personal vehicle users to buses consequent on the increase in the level of service of buses under Indian traffic conditions, has been identified. Logit models for modal shift were then developed using the data of the identified variables. All the calibrated logit models of modal shift (involving bus and motorized two-wheeler, bus and car, bus and auto-rickshaw modes) are found to be statistically significant with satisfactory rho-square (ρ^2) values. The models, when validated using hold-out samples, were found to be valid based on the comparison of the predicted LL values against the originally estimated LL values. The modal-shift models, developed considering the travel-time difference alone as the causal variable, are also found to be statistically valid indicating the relatively high significance of the variable in explaining the modal shifts.

Mode-choice probability curves to depict the possible shift of personal vehicle users to bus have been developed, taking the difference in travel times of the two-modes as the basis.

These serve as a user friendly tool to analyze the possible modal shift for a wide range of values of the involved variables. It can be inferred from the modal shift probability curves (Figures 1, 2 and 3) that at traffic flow conditions pertaining to level of service C, the probability of shift from motorised two-wheeler, car and auto-rickshaw to bus are 0.92, 0.7 and 0.92 respectively on 11.0-m wide road space and the respective values for 14.5-m wide space are 0.58, 0.28 and 0.72.

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