PLANNING FOR DEDICATED BUS LANES ON ROADS CARRYING HIGHLY HETEROGENEOUS TRAFFIC

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ABSTRACT

The desirable goal in passenger transportation is moving more people in fewer vehicles. This goal, in respect of road transport, can be attained by encouraging public transport modes like buses by assigning priority. One of the common bus priority measures is provision of reserved bus lanes on major urban roads to facilitate faster movement of buses. This paper is concerned with modification and validation of a recently developed micro simulation model of heterogeneous traffic flow and application of the model to study the impact of provision of reserved bus lanes on urban roads. The impact of introduction of an exclusive bus lane is measured in terms of reduction in speed of other categories of motor vehicles, due to the consequent reduction in road space, over a wide range of traffic volume. The main finding of the simulation experiment is the quantification of the maximum permissible volume to capacity ratio that will ensure a level of service of C for the traffic stream comprising all the motor vehicles, except the buses, on a typical eight lane divided urban road (if an exclusive bus lane is provided under highly heterogeneous traffic conditions, prevailing in Indian cities). Through this study, a framework for justification of providing exclusive bus lane has also been defined. The results of the study indicate that it is possible to introduce exclusive bus lanes on selected urban roads to enhance the level of service of bus, without much of adverse impact on the level of service of other modes of road transport under the stated roadway and traffic conditions. Provision of exclusive road space for buses, will enhance the level of service of buses and this may also result in shift of some of the personal vehicle users to buses. This study is also concerned with estimation of the probable shift of the personal vehicle users to bus due to increase in its level of service after providing exclusive bus lanes. Mode-choice probability curves to depict the probable modal shift of personal vehicle users to bus has been developed, taking the difference in travel times of the two-modes as the basis, to serve as an user friendly, ready-to-refer tool to predict the possible modal shift for a wide range of the values of the involved variables.

INTRODUCTION

An extremely important but often ignored fact is that the purpose of passenger transportation is to move people; movement of vehicles is a means towards that goal but not a goal in itself. Furthermore, it is always desirable to perform a given amount and quality of transportation with minimum number of vehicles. The growing recognition of this fact has a major impact on the treatment of different modes and therefore on urban transportation polices. Once equal rights are given to all traveling persons instead of vehicles, a standard bus would be given topmost importance than personal vehicles. The use of buses as a main transportation mode has several advantages: (i) it decreases the need for personal vehicles and thus relieves vehicular traffic congestion. (ii) it increases roadway capacity (persons/h). (iii) it provides an affordable, and for many people, necessary alternative to personalized modes, and (iv) it avoids driving stress and can be convenient.

In addition to this, buses should be favored over personal vehicles not only because of the earlier listed specific advantages, but also due to the fact that buses provide basic transport service to entire population, it is more economical, and it has much lower negative side effect to environment. Bus transport system forms an indispensable part of urban transport because of its major role in the social and economic growth of an area. One of the important measures to achieve sustainability in transportation is to maintain and enhance the health and viability of urban public transit modes such as bus. Hence, a great emphasis needs to be given to efficient planning and operation of bus transport system, as it can support existing and future travel demands in urban areas in an efficient way, especially in developing countries like India.

NEED FOR THE STUDY

The road traffic on Indian cities is highly heterogeneous comprising vehicles of wide ranging static and dynamic characteristics. The different types of vehicles present in the traffic on major roads of Indian cities, leaving out the animal drawn vehicles which may be absent or negligible in number, can be broadly grouped into eight different categories as follows: 1. Motorized two-wheelers, which include motor cycles, scooters and mopeds, 2. Motorized three-wheelers, which include auto-rickshaws (three wheeled motorized paratransit vehicles to carry passengers) and tempos (three wheeled motorized vehicles to carry small quantities of goods), 3.Cars including jeeps and small vans, 4. Light commercial vehicles comprising large passenger vans and small four wheeled goods vehicles, 5. Buses, 6. Trucks, 7. Bicycles and 8.Tricycles, which includes cycle-rickshaws (three wheeled pedal type vehicles to carry a maximum of two passengers) and three wheeled pedal type vehicles to carry small amount of goods over short distance. All these categories of vehicles share the same road space without any segregation and occupy any lateral position on the road depending on the availability of road space at a given instant of time without any lane discipline.

Under the said heterogeneous traffic flow conditions, the buses, being relatively larger vehicles, find it difficult to maneuver through the mixed traffic and are subjected to frequent acceleration and deceleration leading to lower speed and discomfort to both the driver and passengers. This also results in enormous delay and uncertainty of travel time to bus passengers. The level of service of bus transit systems in Indian cities is gradually declining due to inadequate capacity and managerial and financial problems, making bus, a less attractive mode of transport. In the absence of an adequate and efficient bus transit system, the potential bus users shift to personal vehicles.

Indian cities desperately need improved and expanded public transport service and not personal vehicles. This requires an increase, both in quantity as well as quality of bus transport service and effective application of demand as well as supply-side management measures. This goal can be attained by encouraging bus transport by assigning priority to it. One of the common bus preferential treatments is provision of reserved bus lanes on major urban roads, to facilitate faster movement of buses, which will make the mode more attractive. The objective of this research work is to study the impact of exclusive bus lanes, introduced on an urban arterial, carrying heterogeneous traffic for a wide range of traffic volume, using computer simulation technique.

REVIEW OF LITERATURE

The general objectives of exclusive bus-lane planning, are: (a) to alleviate existing bus service deficiencies, (b) to achieve attractive and reliable bus service, (c) to serve demonstrated existing demands, (d) to provide reserve capacity for future growths in bus trips, (e) to attract other personal vehicle users, (f) to relate to long-range public transport improvement and (g) to have reasonable operating costs. Exclusive bus lanes can be provided either adjacent to the curb or by the side of the median depending on the operational strategies and road side land use. Provision of exclusive bus lanes is possible only in situations, where the carriageway is of adequate width and a lane can be easily spared for buses. To be successful, the bus lanes should be created for a good length of the road instead of short stretches.

The review of literature on the subject matter indicates that several research works that are related to the subject matter of the present study have been done in the past. Feather et al. (1973) presented some of the experiences gained by the Greater-London-Council bus unit in the design of a wide variety of bus lanes. Cox (1975) studied the exclusive bus-lane schemes that were implemented in the city of Dallas, Texas, USA. He concluded that the assignment of special lanes to buses had not adversely affected the level of service of the vehicular traffic, and there had been a reduction in travel time, a reduction in the number of stoppages, and an increase in speed of buses. Also, the improved level of service of bus transit, due to bus lane implementation, had attracted additional ridership. Tanaboriboon and Toonim (1983) determined the impact on bus movement and car traffic due to provision of with-flow bus lanes on selected streets in the central part of the city of Bangkok, Thailand. The results have shown that, in all the selected streets, bus travel-time savings were realized. Shalaby and Soberman (1994) studied the effect of an urban reserved bus lane on bus travel time on individual road segments. The results of the study suggest opportunities for using reserved bus lanes on a more selective basis along a particular route and the need to reconsider whether taxies should be permitted to use these lanes. The analysis carried out in this study leads to the following conclusions: (i) the bus lane has little impact on bus performance during off-peak periods and when traffic is low (ii) Ridership generally increases after introducing the lane, even without improvements in travel time. Shalaby (1999) used the TRANSYT-7F simulator to examine changes in performance measures of through buses and adjacent traffic following the introduction of reserved lanes for buses in an urban arterial in downtown Toronto, Canada. The results indicate that the bus lane was successful in improving average bus performance compared with the other traffic. The improvement was accompanied by an increase in bus ridership and a reduction in adjacent traffic volumes. Currie et al. (2007) described the methodology developed to evaluate trade offs in the use of the limited road space in Melbourne, Australia for new bus and tram priority projects. The approach employs traffic micro simulation modeling to assess road space reallocation impacts, travel behaviour modeling to assess changes in travel patterns and a social cost-benefit framework to evaluate impacts.

It is found from the review of literature that the reported studies have been conducted under fairly homogeneous traffic conditions and there are no ready-to-apply reference materials available to assist in exclusive bus lane planning and design under highly heterogeneous traffic conditions, in which different types of vehicles share the same road space without any physical segregation. Hence, there is a need to devise appropriate methodology to study the effect of exclusive bus lanes on heterogeneous traffic flow. This paper is concerned with modification and validation of a recently developed micro simulation model of heterogeneous traffic flow and application of the model to study the impact of provision of reserved bus lanes on urban roads.

THE SIMULATION FRAMEWORK

The traffic on Indian roads is highly heterogeneous, comprising vehicles of wide ranging static and dynamic characteristics. Because of this heterogeneity, vehicles do not follow traffic lanes and occupy any lateral position on the road, depending on space availability, for forward movement. The available traffic simulation models are based on lane-based traffic-flow conditions and hence are not applicable to simulate the above mentioned traffic flow on Indian roads. Also, the research attempts made in India to model heterogeneous traffic flow (e.g- Katti and Ragavachari, 1986; Marwah, 1995; Kumar and Rao, 1996; Khan and Maini, 2000) are limited in scope and do not address all the aspects comprehensively. Hence, there was a need to develop appropriate models to simulate heterogeneous traffic flow. Accordingly, a model of heterogeneous traffic flow, named HETEROSIM was developed by Arasan and Koshy, (2005). For the purpose of the simulation, the entire width of the road is considered as single unit without consideration to traffic lanes and the logic for vehicle placement, vehicle movement, etc., which are different from the other simulation models, are based on the observed non-lane based movement of vehicles in the field. Thus, this simulation model is new and is different from the other available models. The modeling framework is explained briefly here to provide the background for the study. For the purpose of simulation, as mentioned earlier, the entire road space is considered as single unit and the vehicles are represented as rectangular blocks on the road space, the length and breadth of the blocks representing respectively, the overall length and the overall breadth of the vehicles. The front left corner of the rectangular block is taken as the reference point, and the position of vehicles on the road space is identified based on the coordinates of the reference point with respect to an origin chosen at a convenient location on the space. The simulation model uses the interval scanning technique with fixed increment of time. For the purpose of simulation, the length of road stretch as well as the road width can be varied as per user specification. The model was implemented in *C++* programming language with modular software design. The flow diagram illustrating the basic logical aspects involved in the program is shown in Figure 1. The simulation process consists of the following major sequential steps related to traffic flow on mid-block sections of roads: (1) vehicle generation, (2) vehicle placement, and (3) vehicle movement.

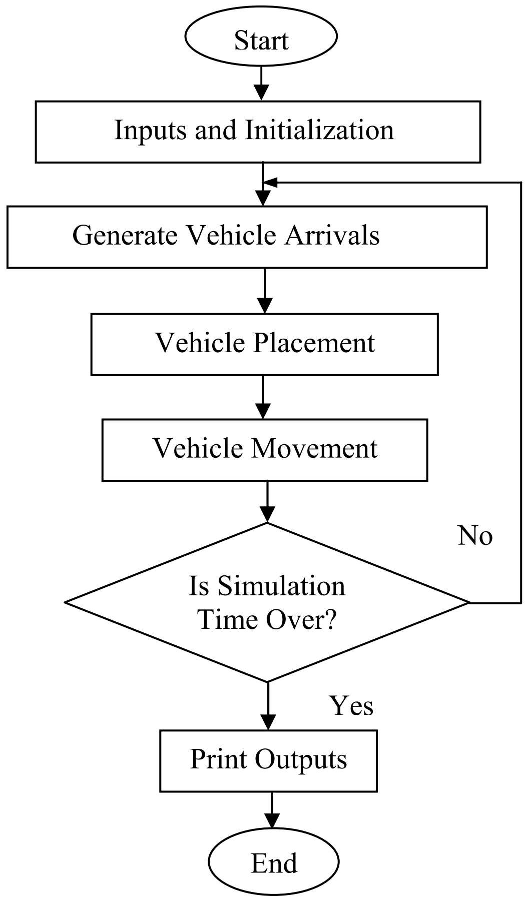


Figure 1. Flow Diagram Depicting Logical Steps of the Model

As the simulation model (HETEROSIM), in its current form, can simulate only unsegregated traffic, modification of the available model was required to make the model suited for the present study. Accordingly, the simulation-program-logic was modified (to segregate buses using exclusive road space) for application in this study.

DATA COLLECTION

Collection and analysis of data play a pivotal role in the development of successful simulation models. Field data should be gathered covering the ranges of anticipated roadway and traffic flow conditions. The required traffic data were collected by observing traffic flow on the Maraimalai Adigalar Bridge, near Saidapet, which falls in the southern part of the metropolitan area of Chennai city, India. The bridge has a six-lane divided road with raised curbs on both sides and it is 250 m long. Since the study stretch is on the bridge, the road geometry is uniform and there is no interference to vehicular movement due to pedestrian traffic as the pedestrian walkway is segregated by a barricade. The traffic flow from Guindy side to Saidapet side (from south to north) was considered for the study. The traffic survey was conducted for one hour using digital video camera by mounting the camera at a vantage point on the road side. The video data were then transferred to computer for further processing. The data inputs required for the model to simulate the heterogeneous traffic flow are: road geometry, traffic volume and composition, vehicle dimensions, minimum and maximum lateral spacing between vehicles, minimum longitudinal spacing between vehicles, free speeds of different types of vehicles, acceleration and deceleration characteristics of vehicles, the type of headway distribution and the simulation period. The data of the relevant characteristics of the vehicles are given in Table 1.

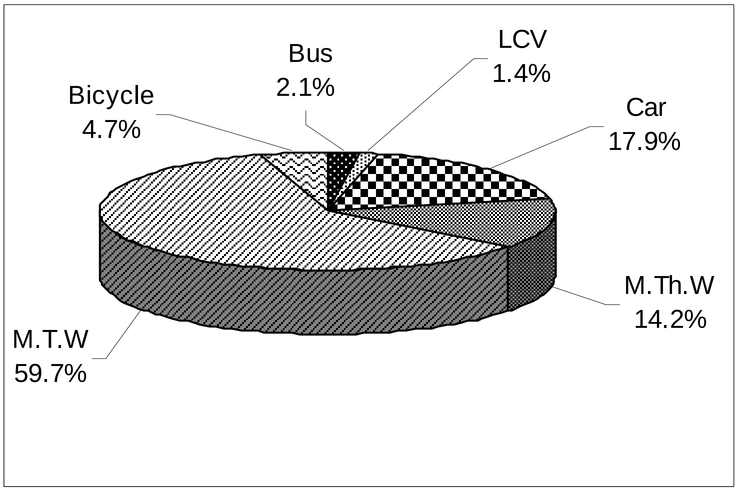
Table 1. Characteristics of Vehicles of the Heterogeneous Traffic

Vehicle Type	Dimensions in m*		Lateral - Clearance Allowance in m		Free Speed in km/h	
	Length	Breadth	Minimum[@]	Maximum[$]	Mean	Standard Deviation.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Bus	10.3	2.5	0.3	0.6	67	7
Truck	7.5	2.5	0.3	0.6	62	9
LCV	5.0	2.0	0.3	0.5	61	7
Car	4.0	1.6	0.3	0.5	72	7
M.Th.W.	2.6	1.4	0.2	0.4	48	8
M.T.W.	1.8	0.6	0.1	0.3	61	10
Bicycle	1.9	0.5	0.1	0.3**	15	2

LCV- Light Commercial Vehicle, M.Th.W – Motorised Three Wheelers, M.T.W - Motorised Two Wheelers
* *Averages of the dimensions of different makes within a vehicle type,* [@] *at zero speed,* [$] *at speeds 60 km/h and more*
*** Maximum clearance at 20 km/h.*

The overall dimensions of all categories of vehicles, adopted from literature (Arasan and Koshy, 2005) are shown in columns (2) and (3) of Table 1. The Minimum Clearance value pertaining to zero speed condition and the maximum Clearance corresponding to a speed of 60 km/h and more, adopted from the literature, are shown respectively in columns (4) and (5) of Table 1. Any vehicle moving in a traffic stream has to maintain sufficient transverse clearances on both sides with respect to other vehicles/curb/ median to avoid side friction. The clearance value is assumed to vary linearly from minimum to maximum depending upon the speed of Vehicles. Lateral clearance allowance is the clearance share pertaining to a vehicle type. For example, if a bus and motorised three wheeler are placed side by side, the minimum lateral clearance between the two vehicles, at zero speed condition will be 0.3 + 0.2 = 0.5 m. Free speeds of different types of vehicles are important input parameters for any traffic flow simulation model. The free speeds of the different categories of vehicles were measured in the field by estimating the time taken by the vehicles to travel a trap length of 30 m at the study stretch of the road during lean traffic periods when the movement of vehicles was not hindered by the presence of other vehicles. The observed mean free speeds of various types of vehicles and the respective standard deviations are shown respectively, in columns (6) and (7) of Table 1.

The composition of the measured traffic flow on the study stretch is as depicted in Figure 2. It was found during traffic-volume count that the number of trucks and tricycles were very small constituting about 0.2 % and 0.15 % respectively, of the total traffic. Hence, these vehicles, for the purpose of analysis, were treated to be equivalent to the suitable other categories of vehicles with similar characteristics. The static and dynamic characteristics of trucks being more or less the same as that of buses, the trucks were considered to be equivalent to buses. Also, each tricycle was treated to be equivalent to two bicycles based on the size and speed of the two categories of vehicles.



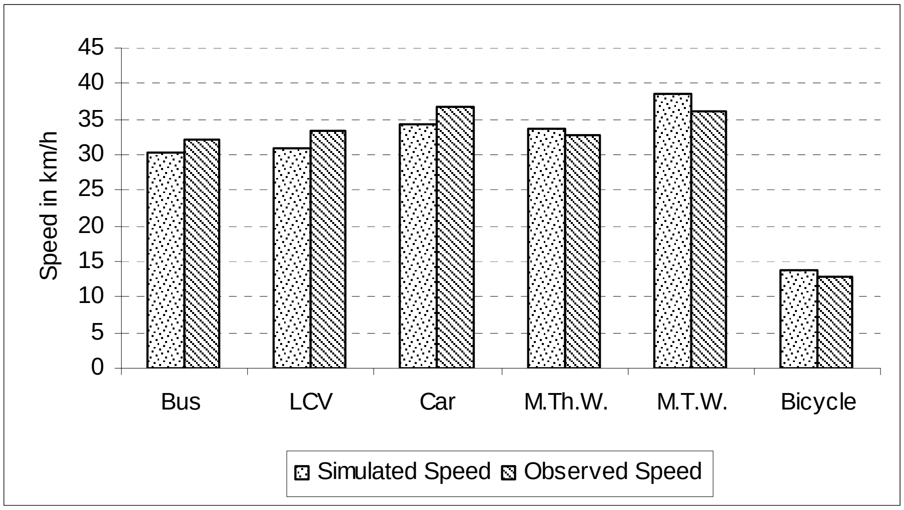
LCV- Light Commercial Vehicles, M.Th.W. – Motorised Three-Wheelers, M.T.W. - Motorised Two-Wheelers

Figure 2. Traffic Composition at the Study Road Stretch

MODEL VALIDATION

Model validation is the process of comparing model results with the corresponding field observed values to ensure that the simulated results realistically represent the real system (field conditions). For validating the simulation model, the traffic flow through a length of 1400 m of road stretch, having same geometric details as the study stretch, was simulated. The initial 200 m length, at the entry point, was used as a warm-up zone. Due to possible unstable traffic flow condition at the exit end, a 200 m long road stretch at the exit end was also excluded from the analysis. To eliminate the initial transient nature of traffic flow, the simulation clock was set to start only after the first 50 vehicles reached the exit end of the road stretch. The simulation runs were made with different random number seeds and the averages of the values were taken as the final model output .The observed roadway condition, traffic volume and composition were given as input to the simulation process. The inter-arrival time (headway) of vehicles was found to fit into negative exponential distribution and the free speeds of different categories of vehicles, based on the results of an earlier study, (Arasan and Koshy, 2005) were assumed to follow a Normal distribution. These distributions, then, formed the basis for input of the two parameters for the purpose of simulation.

For the purpose of model validation, the field observed and simulated mean speeds of each of the categories of vehicles were compared. A comparison of the observed and simulated average speeds of the different types of vehicles is shown in Figure 3. It can be seen that the simulated speed values significantly replicate the field observed speeds for all vehicle types. Also, a paired *t*-test of null hypothesis of no-mean-difference was performed to check for the match between simulated and observed average speeds of vehicles. The calculated value of t (t_0) is 0.39 against the critical value (from 't' table) of 2.57 and thus, it was found that the observed and simulated average speeds agreed at 5% level of significance (95% confidence limit).



LCV- Light Commercial Vehicles, M.Th.W. – Motorised Three-Wheelers, M.T.W. - Motorised Two-Wheelers

Figure 3. Comparison of Observed and Simulated Speeds

IMPACT OF PROVISION OF EXCLUSIVE BUS LANE

The validated simulation model was applied to study the impact of provision of exclusive bus lanes on urban arterials. For this purpose, 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%, Bicycle - 6%) was considered. The roadway width, for the simulation, was fixed as 14.5 m (equivalent to 4 lanes) for each direction. Out of the total width of 14.5 m, a 1.5 m wide road space, adjacent to the curb, was reserved for bicycles (as is the normal practice in Indian cities). First, the traffic flow on the assumed arterial, without bus lane, was simulated. During validation of the model, it was found that three simulation runs (with three different random seeds) were sufficient to get consistent simulation output to replicate the field observed traffic flow. Hence, for model application also, the simulation runs were made with three random number seeds and the average of the three values was taken as the final model output. The simulation was run with volumes varying from a low level to the capacity-flow condition. The speed flow relationship developed, based on the results of the simulation runs, is depicted in Figure 4.

It can be inferred from the plot (Figure 4) that the capacity of 14.5 m wide road space, when there is no exclusive bus lane (all vehicles mixed), is about 9000 vehicles per hour (for the assumed composition) and the corresponding stream speed (calculated as the weighted average of the speeds of all the vehicles) is about 14.5 km/h. As per the Indian Roads Congress (IRC), a statutory body responsible for development of codes and standards for road transport in India, guidelines (IRC, 106-1990), the recommended level of service for urban roads is 'C' and the volume of traffic corresponding to this level of service can be taken as 0.7 times the capacity.

Accordingly, here, the volume of traffic corresponding to level of service C is, 0.7 * 9000= 6300 vehicles per hour.

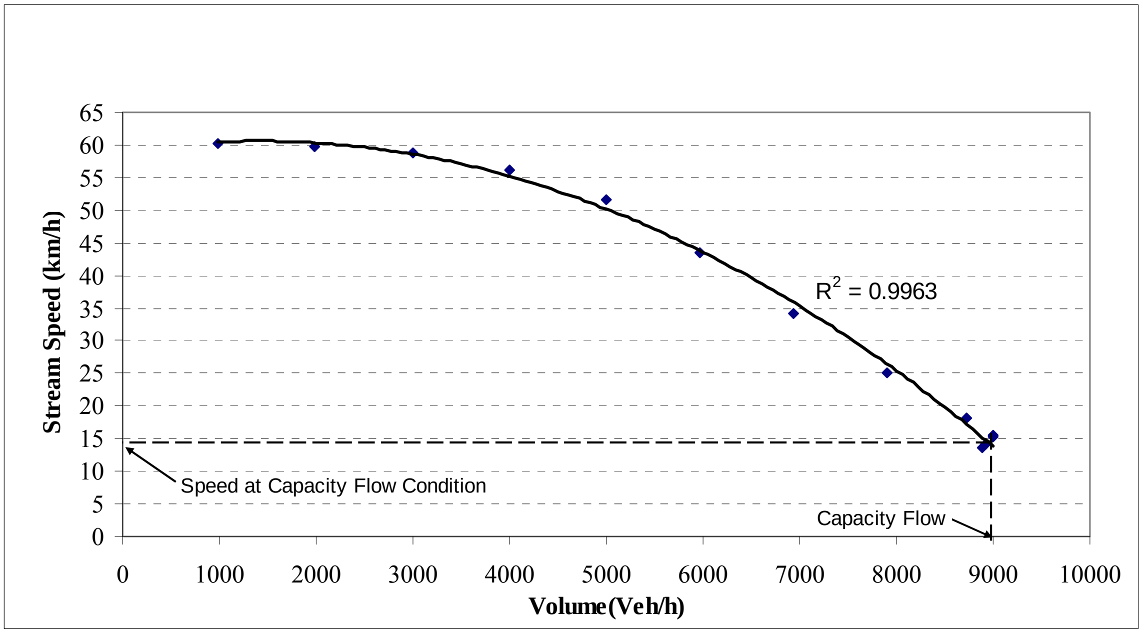


Figure 4. Speed-Flow Curve for 14.5 m Wide Urban Road

To study the impact of provision of exclusive bus lane under the assumed road way condition, for the purpose of simulation, an exclusive bus lane was introduced by the side of the median on the considered stretch of road, and this roadway condition was given as the input to the model by holding the traffic volume and composition to be the same as for the previous case. The layout of the road stretch with the proposed bus lane is shown in Figure 5.

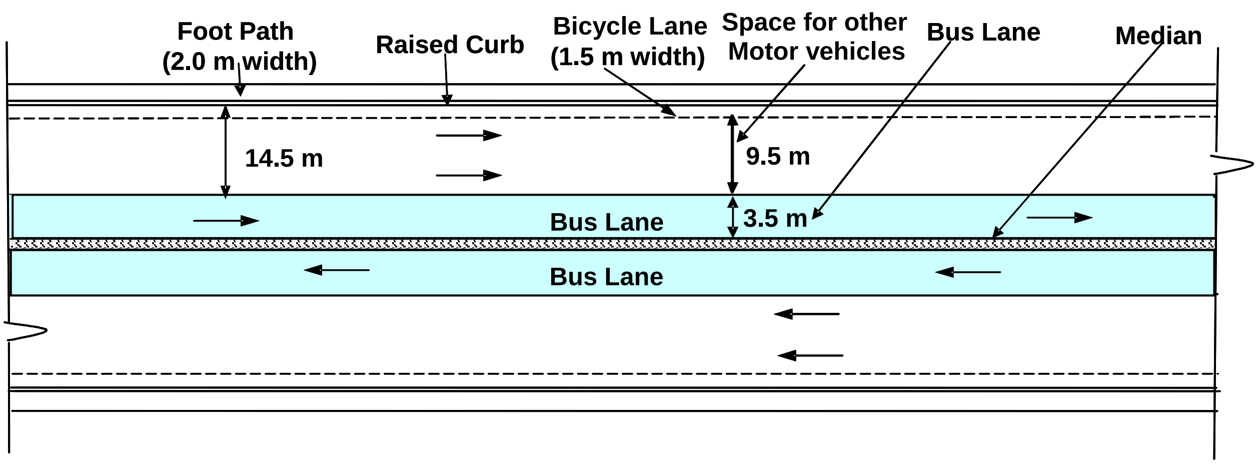


Figure 5. Schematic Layout of the Road Stretch with Exclusive Bus Lane

The simulation runs, after introducing the bus lane, were made similar to the previous case. For these (with bus lane) simulation runs, the traffic volume on the study stretch was varied, as in the case 'without bus lane', from 1000 to 9500 vehicles/h. A simulation run was also made for the traffic volume corresponding to level of service C, which worked out to, 6300 vehicles/h. The speeds maintained by the different types of vehicles for the different simulated traffic-volume levels, for the cases, with and without bus lanes, are shown in Table 2.

Table 2. Speeds of Different Categories of Vehicles on Roadway With and Without Bus Lanes

Traffic Volume* (Vehicles per hour) (1)	Road-way Condition (2)	Running Speed Maintained by Vehicles in Km/h					
		Bus (3)	Truck (4)	LCV (5)	Car (6)	M.Th.W. (7)	M.T.W (8)
1000	WoBL	65.44	56.83	61.82	73.60	49.29	62.93
	WBL	65.78	55.40	60.16	72.91	49.09	62.90
2000	WoBL	63.28	57.62	60.33	71.90	48.91	62.97
	WBL	65.52	53.23	57.29	69.90	48.18	62.58
3000	WoBL	58.66	54.26	58.53	69.37	48.34	62.47
	WBL	65.17	47.71	53.41	65.27	46.80	61.19
4000	WoBL	52.74	48.96	53.60	64.21	47.26	60.61
	WBL	64.96	40.58	47.18	56.97	44.71	57.55
5000	WoBL	45.58	41.65	46.59	55.60	44.78	56.67
	WBL	64.90	34.22	39.08	46.70	40.95	51.36
6000	WoBL	35.75	35.55	37.46	44.04	39.42	48.80
	WBL	64.52	29.00	31.05	36.00	34.17	41.21
6300	WoBL	34.02	31.74	34.98	40.93	37.87	45.95
	WBL	64.41	26.91	28.23	33.14	31.91	38.03
7000	WoBL	27.61	25.94	28.07	32.56	31.98	38.25
	WBL	64.25	22.53	23.98	26.97	27.11	31.33
8000	WoBL	20.36	19.81	21.17	23.44	23.71	27.86
	WBL	64.09	17.75	18.80	20.27	20.93	23.70
9000	WoBL	15.04	14.72	15.65	16.90	17.37	19.71
	WBL	63.76	14.16	14.49	15.24	16.14	18.04
9500	WoBL	12.80	12.58	13.36	14.30	14.73	17.10
	WBL	63.11	12.38	12.81	13.96	13.62	16.08

** Input volume for simulation*
WoBL: Without Bus Lane, WBL: With Bus Lane
LCV- Light Commercial Vehicles, M.Th.W. – Motorised Three-Wheelers, M.T.W. - Motorised Two-Wheelers.

From Table 2, it can be seen that there is increase in the running speed of bus due to provision of exclusive bus lane, at all volume levels. It can be noted that at low volume levels (1000 & 2000 vehicles/h), due to provision of bus lane, there is only marginal increase in bus speed and marginal speed reduction to the speeds of other vehicles. This is mainly because of the near-free-flow condition enjoyed by all categories of vehicles at low volume levels. Also, it can be noted that at higher volume levels (3000 vehicles/h and above), there is a significant speed improvement for bus and a steep decline in the speeds of other categories of vehicles. This implies that at higher volumes, there is a complex closer interaction among the different categories of vehicles and this leads to higher level of adverse impact of the bus lane on the flow of all the other categories of vehicles.

It may be required, while providing exclusive bus lanes, to see that the level of service enjoyed by the other categories of vehicles do not deteriorate beyond an acceptable limit. In this context, it is reasonable to ensure level of service C for the other categories of motor vehicles while providing exclusive bus lanes. Hence, there is a need to have information on the trend of speed variation of the stream of motorised traffic, excluding the buses, for roadway conditions, with and without bus lanes. Accordingly, two plots, on the same set of axes, depicting the variation of the stream speed, over volume-to-capacity ratio, for the two conditions of the road, were made as shown in Figure 6.

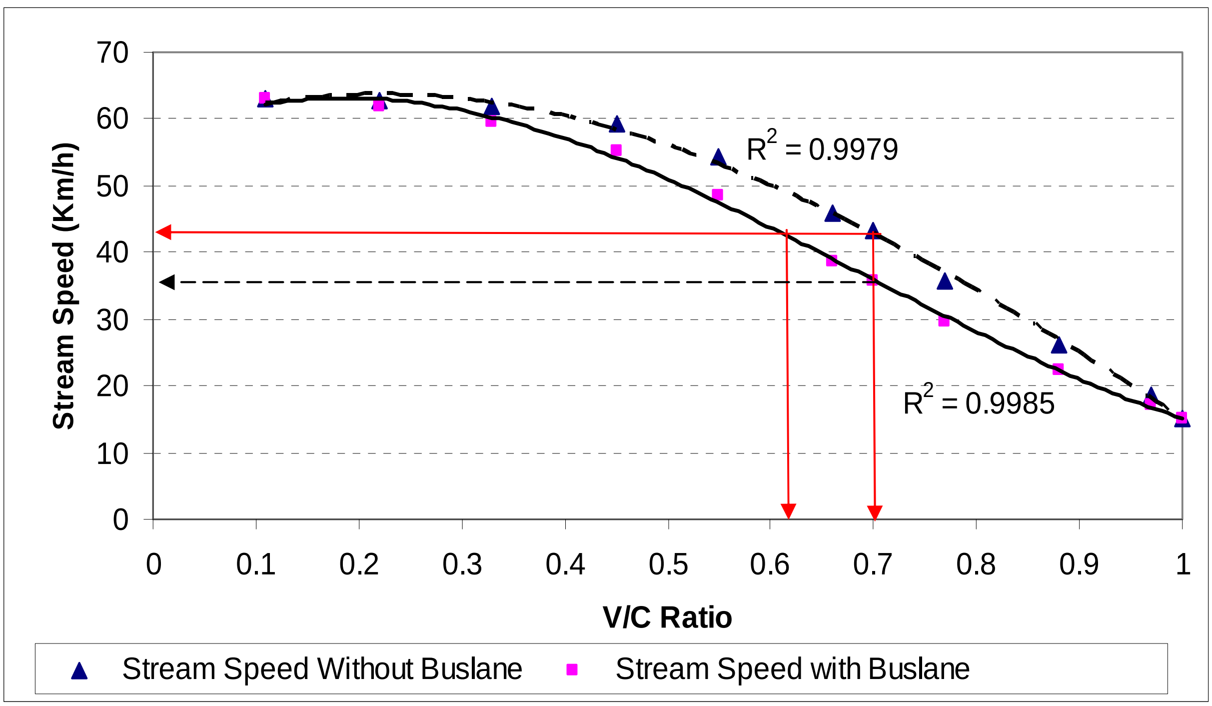


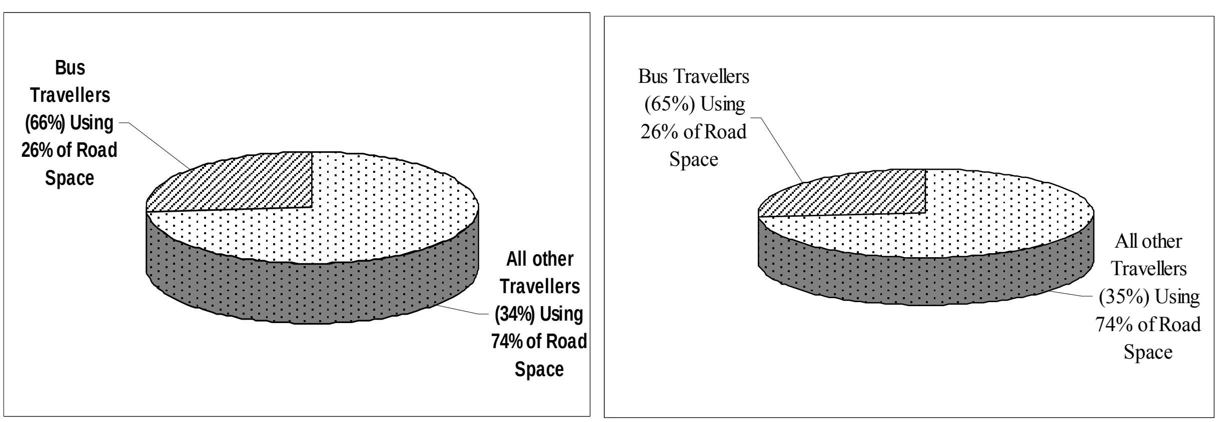
Figure 6. Traffic Stream Speed on the Roadway With and Without Bus Lane

It can be seen that the speed of the traffic stream comprising the other motorised vehicles, when no bus lane is provided, at level of service C (corresponding volume/capacity ratio of 0.7) is 43 km/h and the speed reduces to 36 km/h when a bus lane is provided. If it is desired to provide bus lanes without adversely affecting the level of service of the other categories of motor vehicles, then, the volume of traffic that will ensure the same speed for the other categories of motor vehicles corresponds to a V/C ratio of 0.62, as depicted in the figure. Thus, for the assumed road geometry and traffic composition, provision of exclusive bus lane may not adversely impact the desired level of service required for the other categories of vehicles up to a traffic volume level corresponding to a volume - capacity ratio of 0.62.

JUSTIFICATION FOR EXCLUSIVE BUS LANES

One way of justifying provision of exclusive bus lane is to check for the apportioning of road space based on the number of persons making use of the available road space instead of number of vehicles. For this purpose, it is necessary to estimate the average number of persons using the different categories of vehicles. Accordingly, vehicle-occupancy survey was conducted at typical urban signalized intersections (convenient locations to conduct occupancy survey as the vehicles stop when the signal is red). The occupancy of each of the different types of vehicles was determined by counting the number of persons in each vehicle by standing beside these vehicles when these vehicles were waiting for green signal at the intersections. The average occupancy of the different categories of vehicles, obtained through the survey, is : Bus - 68.81, L.C.V. (Passenger) - 8.36, Car - 2.54, Motorised Three-Wheeler - 2.98, Motorised Two-Wheeler -1.32 and Bicycle -1.14.

By knowing the road width, traffic composition, the width of exclusive bus lane, and the average occupancy of the different categories of vehicles, it is possible to determine the percentage of road space allotted for bus travellers and the travellers using all the other categories of passenger vehicles. For this purpose, the proportion of goods vehicles from among all the other categories of vehicles (excluding buses) is to be subtracted. This was done by first converting all the other categories of vehicles in to equivalent PCUs and subtracting the PCU values corresponding to Trucks and LCV (goods). The percentage road space allocation for bus users and other passenger vehicle users, thus obtained, at LoS 'C' and at Capacity-level flow are shown in Figures 7a and 7b respectively. It can be seen that the road space allocated to bus travelers (consisting more than 60% of the total number of travelers) is relatively much less (only 26% of road space).

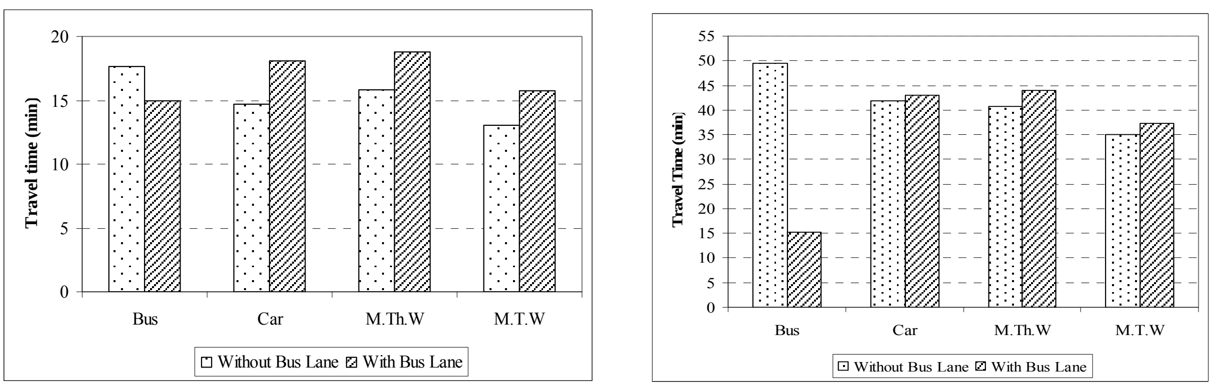


(a) Traffic Flow at Level of Service-C (b) Traffic Flow at Capacity Level

Figure 7. Percentage Road Space Allocation

CHANGE IN TRAVEL TIME

To incorporate the speed reduction that is suffered by buses due to stops, bus stop inventory survey was conducted at typical urban arterial roads in Chennai City. The average dwell time for buses obtained through the survey is 17 Seconds, and the average distance between bus stops is 1.02 km. Then, using the basic equations of motion, the time and distance required for acceleration and deceleration of buses at a bus stop is calculated. Considering a bus route (test section), when an exclusive bus lane is provided, the mean running speed of buses can be up to 65 km/h and the average speed with due consideration to the dwell time and acceleration and deceleration of buses at each stop, the journey speed of buses, while using exclusive bus lane, will be about 39.5 km/h. The difference in travel times of buses and personal vehicles is the important key measure to assess the impact of bus lane. It would be appropriate to assess the impact of bus lane based on the travel time for different categories of vehicles to traverse a 10 km long road stretch. Since the average intersection delay will be the same for both personal vehicles and buses, the intersection delay is not included while calculating travel time. A comparison of the travel time of bus (considering the factors like bus stop spacing and the dwelling times, acceleration and deceleration of buses at bus stops) and other categories of personal vehicles, for both with and without bus-lane conditions, at LoS ‘C’ and capacity-level traffic flow conditions, are shown in Figure 8. It can be seen the reduction in travel time for bus is significant at capacity-flow condition (Fig 8b).



8 (a) Traffic Flow at Level of Service-C 8 (b) Traffic Flow at Capacity

Figure 8. Comparison of Travel Times

MODAL SHIFT DUE TO PROVISION OF EXCLUSIVE BUS LANE

A modal shift occurs when one mode gains a comparative advantage in a travel market over another. The comparative advantage can take various forms, such as costs, capacity, time, flexibility or reliability. Depending on the kind of passengers traveling and their circumstances (socio-economic characteristics, purpose of trip, etc.), the relative importance of each of these factors vary. As provision of exclusive bus lane will enhance the level of service of buses, this may also result in shift of some of the personal vehicle users to buses. This study is also intended to estimate the probable shift of the personal vehicle users (motorized two-wheeler, car and auto-rickshaw) to buses, using an appropriate mode-choice modelling technique, to assess the impact, in respect of modal shift, of providing exclusive bus lanes.

Methodology

As per the available literature, two different approaches are used in mode choice analysis: (1) Revealed Preference (RP) Approach and (2) Stated Preference (SP) Approach. The RP approach has been used to model mode-choice when data on actual choice of mode by travelers 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, SP approach has been adopted for the model development. Since, the modes considered were only bus and any one personal vehicle,(at a time), binary choice model has been used. As the interpretation and specification is straight forward in the logit model than the probit model, the logit model was adopted for the study.

Study Area and Survey Design

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 to bus were collected through home-interview survey conducted in a residential area, named, Todhunter Nagar, 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. 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).

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*). As per this specification, an individual is likely to shift from personal vehicle to bus if the utility of bus mode is more than the utility of personal vehicle. Without loss of generality, the utility of shift is given as the difference between utilities of bus and personal vehicle. Therefore, a traveler is likely to shift from personal vehicle to bus if the utility difference, $U_{diff.} \geq 0$. Therefore, the probability of shift,

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

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

$$V_{diff.} = A_0 + A_1X_1 + \ldots\ldots + A_nX_n$$

Therefore, $$\mathrm{P}_{shift} = \frac{e^{V_{diff.}}}{1+e^{V_{diff.}}} = \frac{e^{A_0+A_1X_1+A_2X_2+......+A_nX_n}}{1+e^{A_0+A_1X_1+A_2X_2+......+A_nX_n}}$$

where,
P_{shift} = probability of shift from personal vehicle to bus mode,
$\mathrm{V}_{\mathrm{diff.}}$ = deterministic utility function of difference in utilities of bus and personal vehicle,
A_0, A_1, A_2… are the model parameters to be estimated,
X_1, X_2… are variables influencing modal shift.

Model Development

Model calibration or estimation involves finding the values of the parameters, which make the observed data more likely under the model specification; in this case, one or more parameters can be judged non-significant and left out of the model. The estimation also considers the possibility of examining empirically certain specification issues, for example, structural and/or functional form of parameters may be estimated. In this study, the stated preference (willingness or otherwise to shift) of the respondent is the dependent variable and gender, age, walking time to bus stop, trip purpose and in-vehicle travel-time difference are the independent variables considered for model estimation. As the dependent variable is discrete in nature, 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.

The users of motorized two-wheelers, auto-rickshaws and cars are likely to shift to buses due to its enhanced level of service after provision of exclusive bus lanes. Hence, the home-interview survey was conducted with 150 two-wheeler users, 100 car users and 100 auto-rickshaw users. The data set pertaining to the 150 two-wheeler users, with their responses for shifting to bus (for five travel-time-difference scenarios), was processed into 750 (5×150) data points 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 observations (20%) for the purpose of validation. For the model-calibration analysis, a software tool, named, Statistical Software Tools (SST) was used. The goodness-of-fit for the calibrated model can be assessed by likelihood ratio index (ρ^2), which is given as,

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

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

For the purpose of model validation, the holdout data set 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, was applied to the hold out sample, to predict the modal shift and the value of Log-Likelihood was calculated. Then, the two values of Log- Likelihood were compared for their closeness. The model-calibration and validation results of the modal-shift analysis for shift from motorized two-wheeler users to bus is shown, as example, in Tables 3 and 4 respectively.

Table 3. Results of Model Calibration

Variable (1)	Parameter Estimate (2)	t-Statistic (3)
Constant	-0.66	-2.44
Gender	0.62	2.23
Age 3	0.67	2.35
Trip-W	0.71	3.03
Walking 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

It can be seen (Table 3) that, the signs of the parameters of the variables are logical. The value of the t-statistic for the different variables, when compared with the corresponding table value, indicate that all the parameter estimates are significant at 5 % level of significance.

Table 4. Results of Model Validation

Description (1)	Value of Model Statistics	
	Model initially calibrated with 600 data points (2)	Model calibrated using hold out sample with 150 data points (3)
Initial LL	-415.89	-103.97
Final LL	-275.96	-69.46
ρ^2	**0.334**	**0.331**
Estimated LL for the model calibrated using hold out sample		-69.46
Calculated LL by applying the model initially calibrated based on 600 data points, in the hold out sample.		-63.06

It can be seen (Table 4) 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.

Modal Shift Probability Curve

To illustrate the usefulness of the modal shift modelling exercise in urban road transport management, the probability of shift of personal vehicle users to bus, for the set of travel time differences, were calculated and plots (mode-choice probability curves) relating the probability of shift and the travel time differences were made in respect of the users of motorized two-wheeler, auto-rickshaw and car (Figures 9, 10 and 11 respectively). As per the Indian Roads Congress (IRC), guidelines (IRC, 106-1990), the recommended level of service for urban roads is 'C'. Hence, the percentage travel-time difference between bus (on exclusive lane) and personal vehicle at volume corresponding to V/C ratio value of 0.7 was determined using the simulation model. Based on the simulation results, the percentage travel-time difference for a two-wheeler is 4. Then, the probability of shifts of two-wheeler user to bus, as per the probability curve (Fig. 9) is 0.58. Similarly, the percentage travel-time difference, obtained through simulation in respect of car, is 16 and the corresponding probability of shift of car users to bus is 0.28 (Fig. 10). In the case of auto-rickshaw users, the travel-time difference is found to be 19 % and the corresponding probability of shift to bus is 0.72 (Fig.11)

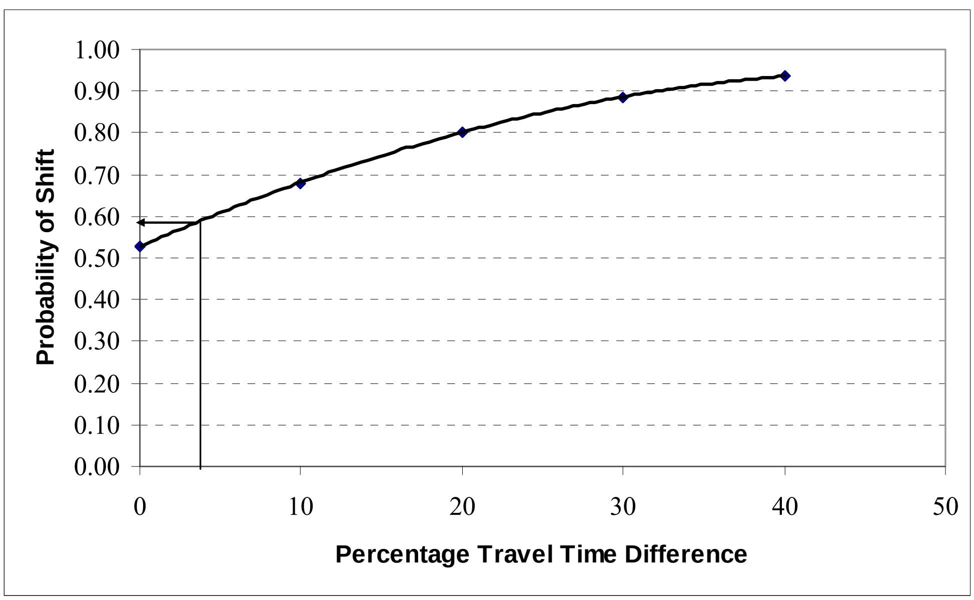


Figure 9. Probability of Shift of Two-Wheeler Users to Bus

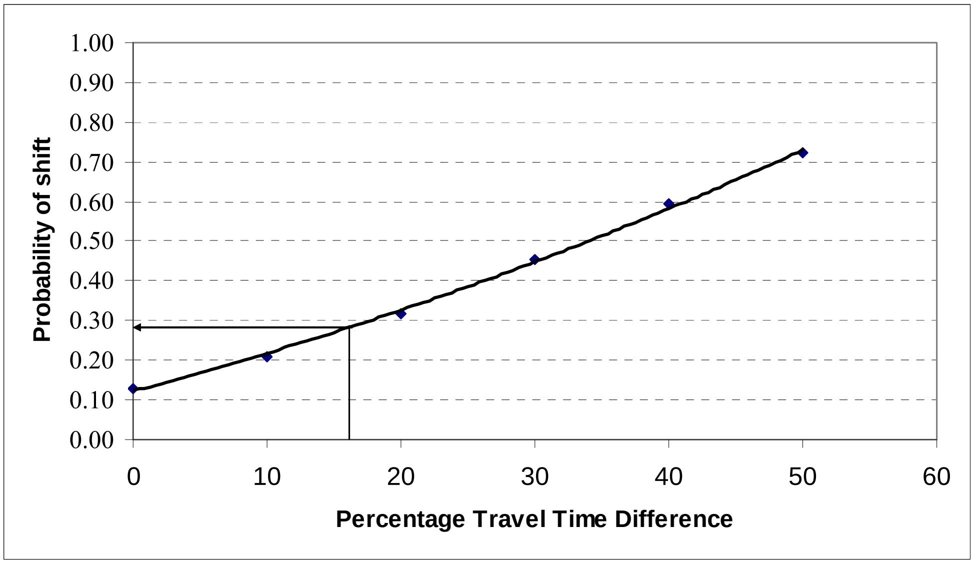


Figure 10. Probability of Shift of Car Users to Bus

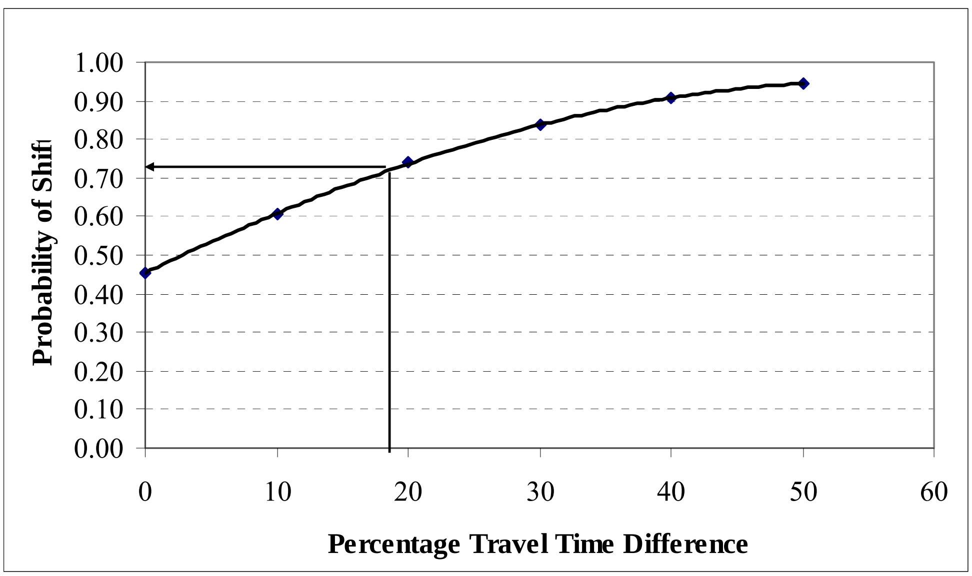


Figure 11. Probability of Shift of Auto-Rickshaw Users to Bus

CONCLUSIONS

Here, the scope is limited to demonstration of the application of the recently developed simulation model of heterogeneous traffic flow, for the purpose of planning of exclusive bus lanes, taking a typical case of roadway and traffic conditions. The developed model may however, find its application in determining similar threshold values of traffic flow for provision of bus lanes under different roadway, and traffic conditions. The bus-lane simulation model, thus, will serve as an important decision making tool in managing the heterogeneous traffic on Indian roads and in other developing countries, where similar traffic scenarios exist.

The following are the important findings of the study:

1. It is found that the simulation model of heterogeneous traffic flow, named ‘HETEROSIM’ is valid for simulating heterogeneous traffic flow for the specific purpose of this study.
2. It has also been found through the study that for the assumed traffic composition, without any exclusive bus lane, the capacity of a 14.5 m wide road with 1.5 m wide bicycle track (included in the total width of 14.5 m), for one way movement of traffic, is about 9000 vehicles per hour.
3. If an exclusive bus lane is provided under the assumed roadway and traffic conditions, then, the maximum permissible volume-to-capacity ratio that will ensure a level of service of C for the traffic stream comprising all the other motor vehicles (except the buses), is about 0.62.
4. When an exclusive bus lane is provided, the mean running speed of buses can be up to 65 km/h (depending on the bus stop spacing and the dwelling times, the corresponding mean journey speed may work out to be about 39.5 km/h) and the mean running speed of the stream of traffic comprising all the other motor vehicles (other than buses) enjoying level of service C, will be 43 km/h.
5. The percentage of road space allotted, in the road considered, to bus travellers (constituting 66% of the total travellers) and the travellers using other modes of transport (constituting only 34% of total travellers) are 26% and 74% respectively for traffic flow at LoS ‘C’. This justifies provision of exclusive bus lanes under the said roadway and traffic conditions.
6. Mode-choice probability curves to depict the possible shift of personal vehicle users to bus (consequent on the introduction of exclusive bus lane) have also been developed to serve as a user friendly tool to analyze the modal shift behaviour for a wide range of the values of involved variable.

REFERENCES

Arasan, V. T.,and Koshy, R.Z.(2005). Methodology for modeling highly heterogeneous traffic flow. *J.Transp. Eng.,* 131(7), 544 – 551.

Alvinsyah, Soehodho, S., and Nainggolan, P.J. (2005). Public transport user attitude based on choice model parameter characteristics, (case study: Jakarta bus way system). *Journal of Eastern Asia Society for Transportation Studies*, 6, 480-491.

Cox, A.M.(1975).Reserved bus lanes in Dalls, Texas. *J.Transp. Eng.,* 101(4), 691-705.

Currie, G., Sarvi, M., Young, W. (2007). A new approach to evaluating on-road public transport priority projects: balancing the demand for limited road-space. *Transportation,* 34(4), 413-428.

Feather, D., Cracknell, J.A., and Forster, J.A.(1973).Bus priority in greater London – Development of bus lane schemes. *Traffic Eng.Control,* 14(9), 429-432.

Indian Road Congress (IRC).(1990). *Guidelines for Capacity of Urban Roads in Plain Areas.* IRC :106, New Delhi, India.

Katti, V.K., and Raghavachari, S. (1986). Modeling of mixed traffic with speed data as inputs for the traffic simulation models. *Highway Research Bulletin*, 28, Indian Roads Congress,35-48.

Khan, S.I., and Maini, P. (2000). Modeling heterogeneous traffic flow. *Transp.Res.Rec.,*1678, Transportation Research Board, Washington, D.C,234- 241.

Kumar, V.M., and Rao, S.K.(1996). Simulation modeling of traffic operations on two lane highways. *Highway Research Bulletin*, 54, Indian Roads Congress, 211-237.

Marwah, B.R. (1995). Simulation and Animation of Traffic Flow on Highways with Intersections. *Proc., of International Conference on New Horizons in Road and Road Transport*, Roorkee, 989-999.

Ortuzar, J.D., and Willumsen, L.G. (2001). "Modelling Transport" 3rd Edn, *John Wiley& Sons Ltd.* England.

Shalaby, S.A., and Soberman, M.D.(1994). Effect of with flow bus lanes on bus travel times. *Transp. Res.Rec.*,1433, Transportation Research Board, Washington,D.C, 25- 30.

Shalaby, S.A. (1999). Simulating performance impacts of bus lanes and supporting measures. *J.Transp.Eng.,* 125(5), 390-397.

Tanaboriboon, Y., and Toonim, S. (1983). Impact study of bus lanes in Bankok. *J.Transp. Eng.,* 109(2), 247-255.