MICRO-SIMULATION STUDY OF BUS PRIORITY ON ROADS CARRYING HIGHLY HETEROGENEOUS TRAFFIC

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KEY WORDS

Heterogeneous Traffic, Simulation, Exclusive Bus Lane, Impact Assessment, Level of Service.

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. This paper is concerned with the conceptual framework of a micro simulation model of highly heterogeneous traffic flow and application of the model to study the impact of exclusive bus lanes introduced on urban arterials. The impact is measured in terms of the reduction in speed of other categories of motor vehicles, due to the consequent reduction in road space. The results of the study indicates that it is possible to introduce exclusive bus lanes on selected urban roads to enhance the level of service of the bus, without much adverse impact on the level of service of other modes of road transport.

INTRODUCTION

The road traffic in the cities of developing countries like India is highly heterogeneous comprising vehicles of wide-ranging static and dynamic characteristics. The different types of vehicles present in the traffic in Indian cities 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 transit vehicles to carry a maximum of three 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 include cycle-rickshaws -three-wheeled pedal type transit vehicles to carry a maximum of two passengers and three wheeled pedal type vehicles to carry small amount of goods over short distances. All these categories of vehicles share the same road space without any physical segregation. By virtue of their wide-ranging static and dynamic characteristics, the vehicles 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 these heterogeneous traffic flow conditions, the buses, being relatively large 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 to bus passengers and consequently, the level of service of buses gets reduced considerably making buses a less attractive mode of transport.

The road traffic in Indian cities has grown at a very steep rate in the recent past making the available transport infrastructure inadequate. As augmentation of urban transport infrastructure is expensive, there is a need to find alternative solutions to the problem. One way is to devise methods for optimal utilization of the available infrastructure (road space) in such a way that the carrying capacity of the roadway, in terms of number of persons transported, is enhanced. This may be achieved by providing priority for buses, which will facilitate faster movement of more people in fewer vehicles resulting in reduced congestion. This paper is concerned with the conceptual traffic simulation framework of highly heterogeneous traffic flow and application of the model to study the impact of provision of exclusive bus lanes on urban roads.

SCOPE

Introduction of exclusive bus lanes requires comprehensive study of the flow characteristics of the traffic as a whole, and this can be done by using appropriate modeling technique. This paper is concerned with validation of a recently developed micro simulation model of heterogeneous traffic flow (Arasan and Koshy, 2005) and application of the model to study the impact of provision of reserved bus lanes on urban roads.

THE SIMULATION MODEL

Simulation models may be classified as being static or dynamic, deterministic or stochastic, and discrete or continuous. A simulation model which does not require any random values as input is generally called *deterministic*, whereas a *stochastic* simulation model

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has one or more random variables as inputs. Random inputs lead to random outputs and these can only be considered as estimates of the true characteristics of the system being modeled. Discrete and continuous models are defined in an analogous manner. The choice of whether to use a discrete or continuous simulation model is a function of the characteristics of the system and the objectives of the study (Banks et al. 2004). For this study, a dynamic stochastic type discrete event simulation is adopted in which the aspects of interest are analysed numerically with the aid of a computer program.

As this study pertains to the heterogeneous traffic conditions prevailing in India, the available traffic simulation models, which are based on homogeneous traffic conditions, where clear lane and queue discipline exists, are not applicable to study the heterogeneous traffic flow characteristics. Also, the research attempts made 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 (Arasan and Koshy, 2005). The modeling framework is explained briefly here to provide the background for the study. For the purpose of simulation, 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 as Figure 1. The simulation process consists of the following major sequential steps related to traffic flow on mid-block section of roads: (1) vehicle generation, (2) vehicle placement, and (3) vehicle movement.

Vehicle Generation

In a stochastic traffic simulation process, the vehicles arrive randomly, and they may have varying characteristics (e.g. speed and vehicle type). Traffic-simulation models therefore, require randomness to be incorporated to take care of the stochasticity. This is easily done by generating a sequence of random numbers. For generation of headways, free speed, etc., of vehicles, the model uses several random number streams, which are generated by specifying separate seed values. Whenever a vehicle is generated, the associated headway is added to the sum of all the previous headways generated to obtain the cumulative headway. The arrival of a generated vehicle occurs at the start of the warm-up road stretch when the cumulative headway equals the simulation clock time. At this point of time, after updating the positions of all the vehicles on the road stretch, the vehicle-placement logic is invoked.

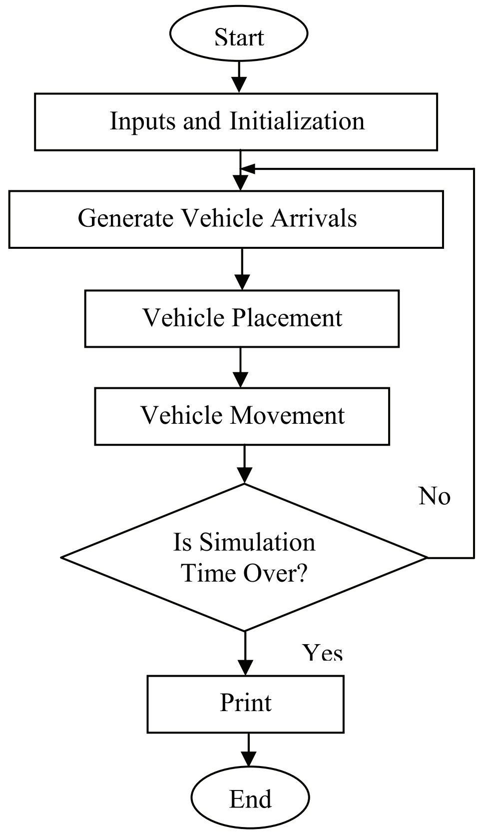


Figure 1: Flow Diagram of the Simulation Model

Vehicle Placement

Any generated vehicle is placed at the beginning of the simulation stretch, considering the safe headway (which is based on the free speed assigned to the entering vehicle), lateral gap and the overall width of the vehicle with lateral clearances. If the longitudinal gap in front is less than the minimum required safe gap, the entering vehicle is assigned the speed of the leading vehicle, and once again the check for safe gap is made. If the gap is still insufficient to match the reduced speed of the entering vehicle, it is kept as backlog, and its entry is shifted to the next scan interval. During every scan interval, the vehicles remaining in the backlog are admitted first, before allowing the entry of a newly generated vehicle.

Vehicle Movement

This module of the program deals with updating the positions of all the vehicles in the study road stretch sequentially, beginning with the exit end, using the formulated movement logic. Each vehicle is assumed to accelerate to its free speed or to the speed limit specified for the road stretch, whichever is minimum, if there is no slow vehicle immediately ahead. If there is a slow vehicle in front, the possibility of overtaking the slow vehicle is explored. During this phase, the free longitudinal and transverse spacing available for the subject vehicle (fast moving vehicle), on the right and left sides of the vehicle in front (slow vehicle), are calculated. If the spacing is found to be adequate (at least equal to the movable distance of the vehicle intending to overtake plus the corresponding minimum spacing in the longitudinal direction and the minimum required lateral spacing in the transverse direction), an overtaking maneuver is performed. If overtaking is not possible, the fast vehicle decelerates to the speed of the slow vehicle in front and follows it. The model is also capable of displaying the animation of simulated traffic movements through mid block sections. The animation module of the simulation model displays the model's operational behavior graphically during the simulation runs. The snapshot of animation of traffic flow, obtained using the animation module of HETEROSIM, is shown in Figure 2. The model has been applied for a wide

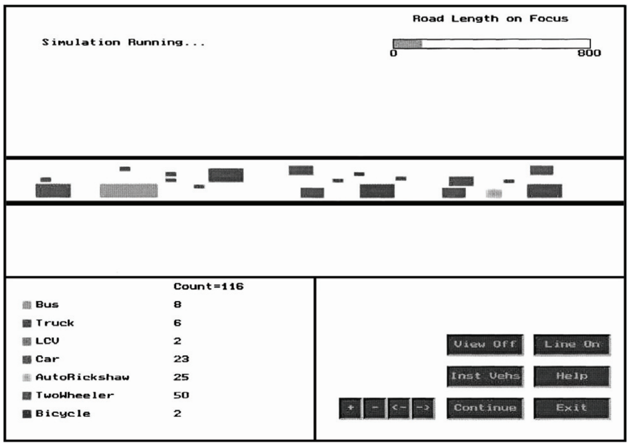


Figure 2: Snapshot of the Animation of Simulated Heterogeneous Traffic Flow

range of traffic conditions (free flow to congested flow conditions) and has been found to replicate the field observed traffic flow to a satisfactory extent through an earlier study (Arasan and Koshy, 2005).

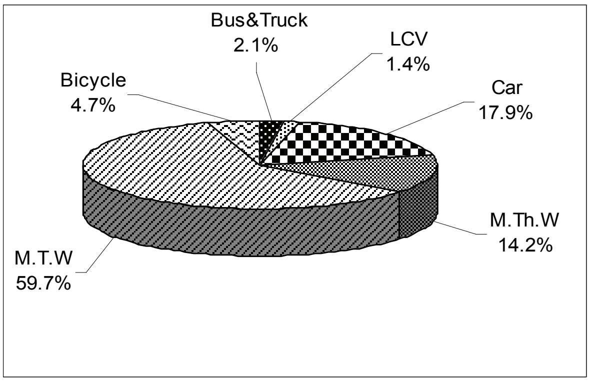
DATA COLLECTION

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, 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 was considered for the study. The width of the carriageway is 12m for the traffic stream considered. The traffic flow was recorded for one hour using a video camera mounted on the terrace of an adjacent building, which enabled recording of all the traffic flow characteristics at the same time. The video data were then transferred to computer for further processing. The 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 relevant characteristics of the vehicles are given in Table 1. The composition of the measured traffic volume on the study stretch is as depicted in Figure 3.

Table 1: Characteristics of Vehicles of the Heterogeneous Traffic

Vehicle Type	Dimensions in m		Lateral - Clearance Allowance in m		Free Speed in km/h	
(1)	Length (2)	Breadth (3)	Minimum (4)	Maximum (5)	Mean (6)	Standard Deviation. (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



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

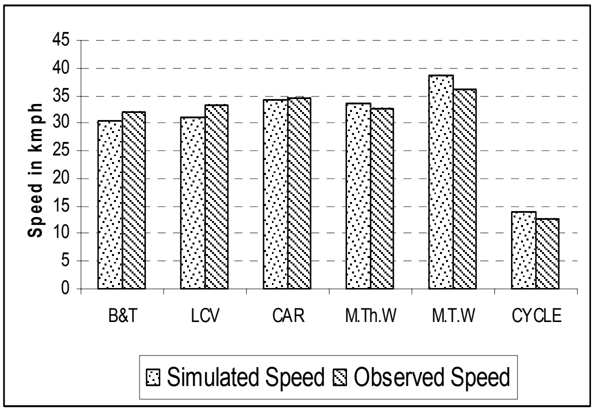
Figure 3: Traffic Composition at the Study Road Stretch

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 literature (Arasan and Koshy, 2005) 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 will be 0.3 + 0.2 = 0.5 m. Knowledge of speed characteristics of various categories of vehicles is essential for the calibration and validation of simulation models. 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 also noted by estimating the time taken by the vehicles to travel a trap length of 30 m on the study stretch of the road during lean traffic periods when the movement of vehicles are 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 observed traffic volume and composition were given as input to the simulation process. The simulation runs were made with different random number seeds and the averages of the values were taken as the final model output. The model output includes the number of each category of vehicle generated, values of all the associated headways generated, number of vehicles present over a given road length at any point of time, number of overtaking maneuvers made by each vehicle, speed profile of vehicles, etc.

MODEL VALIDATION

For validating the simulation model, the traffic flow through a length of 1400 m of the study stretch was simulated. 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 4. 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. It was found that the observed and simulated average speeds agreed at a 5% level of significance (95% confidence limit).



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

Figure 4: Observed and Simulated Speeds

MODEL APPLICATION

The 'HETEROSIM' model can be applied to study a host of heterogeneous traffic scenarios on urban road links. Here, the application of the model is specific to study the impact of provision of an exclusive bus lane. For this purpose, a traffic composition representing the mean composition of traffic on the major roads of Chennai, India was considered (Figure 5).

The roadway width for the simulation was fixed as 11 m (3 lanes) in each direction (most common type of urban arterial in Indian cities). Out of the total width of 11 m,

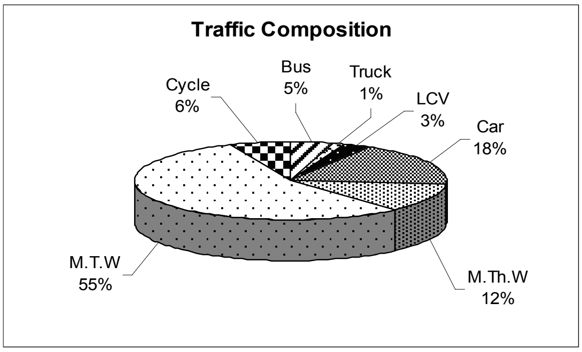


Figure 5: Representative Traffic Composition

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. 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 6.

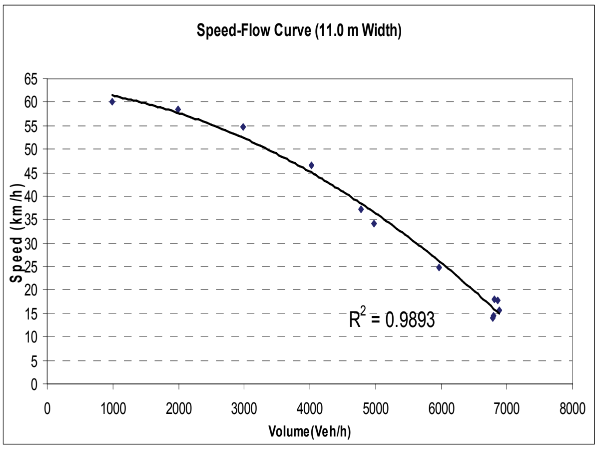


Figure 6: Speed Flow Curve for 11m Wide Urban Road

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 averages of the three values were taken as the final model output.

It can be inferred from the plot (figure 6) that the capacity of 11 m wide road space, when there is no exclusive bus lane (all vehicles mixed), is about 6900 vehicles per hour and the corresponding stream speed is about 16 km/h. As per the Indian Roads Congress-a statutory body responsible for development of codes and standards for road transport in India, guidelines (IRC, 106-1990), the acceptable 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*6900=4830, say 4800 vehicles per hour.

To study the impact of provision of exclusive bus lane under the assumed road condition, for the purpose of simulation, an exclusive bus lane was introduced by the side of the median on the stretch of road, which will be used by all the buses 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 assumed layout of the road stretch with the proposed bus lane is shown in Figure 7. 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 7000 vehicles/h. A simulation run was also made with traffic volume corresponding to level of service C, namely, 4800 vehicles/h. The speeds maintained by the different types of vehicles for the different simulated traffic volume levels are shown in Table 2.

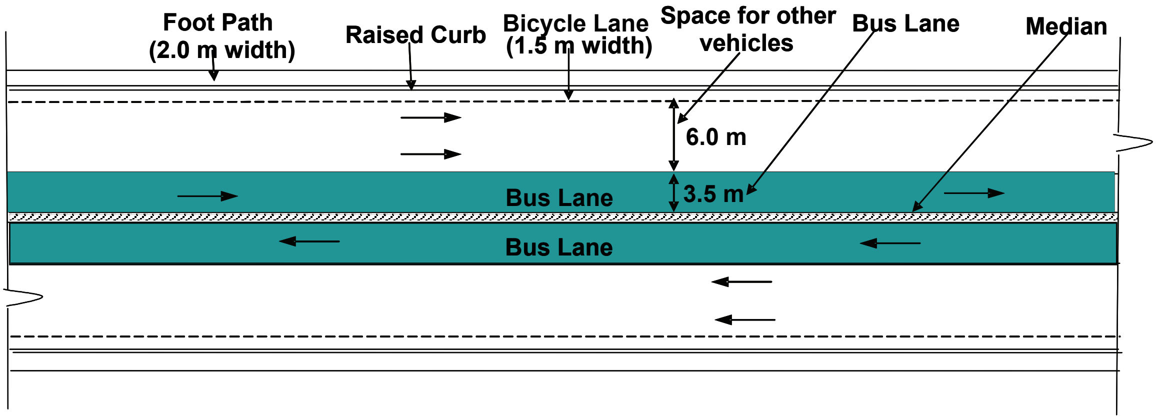


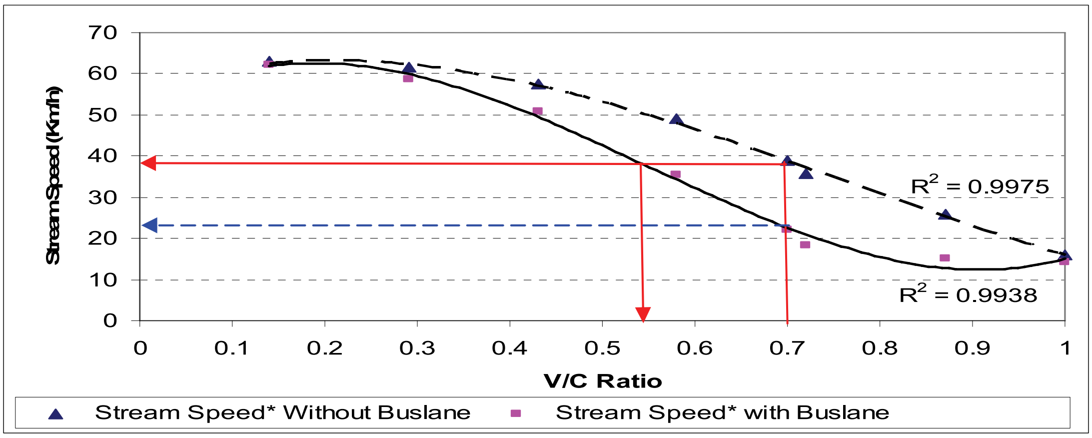
Figure 7: Schematic Layout of the Road Stretch with Exclusive Bus Lane

Table 2: Speeds of Different Categories of Vehicles on the Roadway with and without Bus Lanes

Traffic Volume (Vehicles/h) (1)	Road-way Condition (2)	Speed Maintained by Vehicles in Km/h						
		Bus (3)	Truck (4)	LCV (5)	Car (6)	M.Th.W (7)	M.T.W (8)	Bicycle (9)
1000	WoBL	63.5	55.6	60.8	72.8	48.9	62.9	14.5
	WBL	66.2	52.9	58.5	70.4	48.3	62.9	13.9
2000	WoBL	58.8	53.7	58.4	68.9	48.0	62.2	14.5
	WBL	65.9	48.4	53.9	61.9	46.6	60.6	13.3
3000	WoBL	51.2	45.8	51.1	60.9	46.1	59.4	14.5
	WBL	65.5	41.4	45.3	49.9	42.7	53.3	13.1
4000	WoBL	40.3	37.6	41.2	47.6	41.6	51.9	14.5
	WBL	65.2	29.3	30.4	33.6	32.0	37.3	12.9
4800	WoBL	30.3	28.2	31.7	35.3	34.2	41.8	14.4
	WBL	65.1	19.9	19.5	20.4	20.9	22.9	12.9
5000	WoBL	28.3	26.8	28.9	32.7	32.0	37.9	14.4
	WBL	65.1	16.7	16.3	16.9	17.2	19.3	12.8
6000	WoBL	20.9	20.5	21.6	23.3	23.7	27.4	13.9
	WBL	65.4	14.3	13.9	13.9	14.5	15.5	12.2
7150	WoBL	14.7	14.6	14.9	15.2	15.3	16.5	12.5
	WBL	64.5	13.7	13.5	13.4	13.5	14.9	12.2

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 speed of bus due to provision of exclusive bus lane, at all volume levels. It can be noted that at lower volume levels (1000 & 2000 vehicles/h), due to provision of bus lane, there is marginal increase in bus speeds and marginal speed reduction to 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 interaction among the different categories of vehicles and this creates a negative impact of the bus lane on the flow of all the other categories of vehicles. In the case of the other categories of motorised vehicles, the exact value of speed reduction varies between vehicle types. It is important, while providing exclusive bus lanes, to see that the levels of service enjoyed by the other categories of vehicles do not deteriorate beyond the acceptable limit. In this context, it is reasonable to ensure level of service C (recommended as acceptable level of service on urban roads by Indian Roads Congress (IRC)) for the other categories of motor vehicles while providing an exclusive bus lane. 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. Hence, 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 8.



* Stream of all motorised vehicles except buses

Figure 8: Traffic Stream Speed on the Roadway with and without Bus Lane

It can be seen that the speed of the stream involving the other motorised vehicles, when no bus lane is provided, at level of service C (corresponding volume/capacity ratio of 0.7) is 39 km/h and the speed reduces to 22 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 0.53 as depicted in the figure. Thus, for the assumed road geometry and traffic composition, provision of exclusive bus lane may not adversely impact the minimum level of service required for the other categories of vehicles up to a traffic volume to capacity ratio of 0.53. The two plots also enable understanding of the traffic flow conditions, in terms of, speed over a range of volume-to-capacity ratios for the two roadway conditions (with and without bus lane).

CONCLUSIONS

The simulation model of heterogeneous traffic flow named, HETEROSIM is found to be valid for simulating heterogeneous traffic flow for the specific purpose of this study. It has been found through the study that for the assumed traffic composition, without any exclusive bus lane, the capacity of a 11 m wide road with 1.5 m wide bicycle track (included in the total width of 11 m), for one way movement of traffic, is about 6900 vehicles per hour.

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 0.53. 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 40 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 39 km/h.

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