Microscopic Simulation for Modeling Exclusive Stopping Space for Motorcycles under Non-lane Based Mixed Traffic Conditions

Authors

Gowri Asaithambi
(Corresponding author)
Assistant Professor
Department of Civil Engineering
National Institute of Technology Karnataka,
Surathkal, Mangalore-575025, INDIA
E-mail: gowri_iitm@yahoo.co.in
Tel: +91-824-2473971

R. V. Yogesh Kumar
Former Graduate Student
Transportation Engineering Division
Department of Civil Engineering
Indian Institute of Technology Madras
Chennai-600 036, INDIA

and

R. Sivanandan
Professor
Transportation Engineering Division
Department of Civil Engineering
Indian Institute of Technology Madras
Chennai-600 036, INDIA

Abstract

Mixed traffic flow with high composition of motorcycles is a common situation in many urban areas in South Asian countries like India. It consists of vehicles having diverse static and dynamic characteristics. This type of traffic is characterized by lack of queue and lane disciplines. Motorcycles, due to their smaller size, have greater freedom to manoeuver in a mixed traffic stream. They tend to accumulate near the stop line by weaving through gaps between other vehicles during the red phase. The provision of Exclusive Stopping Space for Motorcycles (ESSM) near the stop line is believed to be beneficial in discharging the motorcycles faster, thereby enhancing the efficiency of the intersection.

A microscopic traffic simulation model for a signalized intersection developed specifically for mixed traffic was used in this study. The model was calibrated and tested with data from Chennai city, India. This model was used to simulate traffic flow at an intersection assuming the presence of ESSM. The efficacy of ESSM was evaluated by varying the vehicular composition, traffic volume and ESSM lengths. The findings show that for certain composition, volume levels and lengths of ESSM, delays to vehicles decrease, thereby indicating its benefits.

Keywords: Mixed Traffic; Signalized Intersections; Microscopic simulation Model; Motorcycles; Exclusive Storage Space for Motorcycles

1.0 INTRODUCTION

In urban areas in India, vehicles do not follow lanes and occupy any available lateral position on the road space. Moreover, in mixed traffic, a vehicle is influenced by more than one leading vehicle and its movements are not restricted to a lane. Also, the vehicular composition includes motorcycles, cars (including jeeps and small vans), buses, auto-rickshaws (three-wheeled motorized vehicles), light commercial vehicles (LCV), trucks, and non-motorized vehicles such as bicycles.

At intersections, homogeneous traffic consists of a stream of identical vehicles (mostly cars) following lane discipline. But in mixed traffic conditions, mix-up of vehicles is high and vehicles do not follow ordered queue and lane discipline (Fig. 1). This often leads to complex maneuvers and interactions with road users. These issues render the understanding and modeling of mixed traffic flow difficult. Moreover, intersections become bottlenecks with increasing traffic demand that lead to enormous delays. The term “queue” in the paper refers to the accumulation of vehicles near the stop line during red phase, though not waiting in orderly formation.

FIGURE 1 Homogeneous (left) and Mixed Traffic (right) Characteristics at Signalized Intersections

Motorcycles are relatively small in size, have greater maneuverability, flexibility and have freedom to park practically anywhere. Motorcycles have the agility and the capability to weave through queues in congested areas. They will not follow the “First In First Out” rule at intersections with queues. They will often attempt to get in between queuing vehicles to get to the front of the queue and reach the stop line (Fig. 2). As a result, many motorcycles will depart together within a very short period of time once the traffic signal turns green. This phenomenon will generate a motorcycle wave at the beginning of green phase.

Only a few cities around the world have attempted to segregate motorbikes from the general traffic. Special motorbike lanes have been built in Taipei, China, Malaysia, Brazil, and a few other countries (Hsu *et al.* 2003). The purpose of this segregation has been to improve the capacity of the roadway and to reduce accidents. Special treatment at intersections is given to motorcycles to facilitate their clearance from the intersection quickly, and thereby reduce delays to other vehicles.

This study is motivated by the following considerations: Research studies on motorcycle behavior at intersections under mixed traffic are relatively sparse compared to studies on homogeneous traffic in developed countries. However, a growing number of researchers have developed simulation based models for mixed traffic providing important insights. The main focus of this paper is to study the impact of Exclusive Stopping Space for Motorcycles (ESSM) on delays at signalized intersection under mixed traffic conditions by varying traffic compositions using microscopic simulation model. The following are the specific objectives of the study:

- To modify the existing simulation model to simulate the traffic flow on Exclusive Stopping Space for Motorcycles (ESSM) near the stop line at a signalized intersection
- To evaluate the efficacy of ESSM near the stop line by varying the traffic composition, volume and ESSM length

FIGURE 2 Motorcycle Behavior at a Signalized Intersection in Chennai city, India

2.0 LITERATURE REVIEW

The scope of this literature review is restricted to simulation models for intersections and motorcycle behavioral studies under mixed traffic flow characteristics.

Various simulation models were developed for signalized intersection under heterogeneous traffic conditions (Bandyopadhyay 2001; Arasan and Kashani 2003; Marwah *et al.* 2006; Mathew and Radhakrishnan, 2010). In most of the above mixed traffic studies, limited aspects on queue formation and dissipation at intersections have been addressed. Moreover, impact of traffic control and management measures have been studied in a limited way. For instance, they do not adequately consider the share of road space by straight-through, left and right turning vehicles in the absence of lane discipline. The unique behavior such as seepage by motorcycles to front of queues has not received adequate attention.

Haque *et al.* (2008) made an attempt to examine the exposure of motorcycles at signalized intersection. The tendency of motorcycles to move to the front of the queue increases the likelihood of a higher motorcycle discharge during the initial period of green. Furthermore, the ability of motorcycles to accelerate faster and easier makes them more prone to be involved in crashes during the initial period of green. Rongviriyapanich *et al.* (2010) investigated the effects of motorcycles on traffic operations at signalized intersections. Major finding of the study is that the effects of motorcycles could be measured in terms of an increase in the start-up lost time of signal phase. A microscopic traffic simulation is developed so that effects of motorcycles can be taken into account in the planning and management of urban streets. Vien *et al.* (2008) discussed the characteristics of motorcyclists travel behavior at signalized intersections in Malaysia and their effects on the estimation of saturation flow. Linh *et al.* (2010) proposed a microscopic model for motorbike dominated traffic based on Cellular Automata modeling approach. Lee *et al.* (*2012*) compared certain kinematic features of motorcycles with those of passenger cars. In urban networks, the observable parameters indicate that motorcycles have shorter safety gaps, higher speeds and severer acceleration and deceleration rates than do passenger cars. The finding provides a possible explanation for why motorcyclists are more likely to accept smaller safety gaps and higher speeds even if they would be vulnerable to road accidents. Minh *et al.* (2012) proposes a maneuverability model framework for motorcycles in queues at signalized intersections considering the dynamic motorcycle's lane. The model includes (i) a dynamic motorcycle's lane to identify the current, left, and right lanes of the subject motorcycle, (ii) a threshold distance to determine when a motorcyclist starts to consider maneuvering, (iii) a lane selection model to identify the lane preferred by a motorcyclist, and (iv) a gap acceptance model to describe whether or not the lead and lag gaps are acceptable for maneuvering. In Taiwan, motorcycles are allowed to store behind the stop line at few intersections (Lee 2008). None of the above studies have studied the influence of ESSM on delays to vehicles at intersections.

The influence of dominant vehicle types (notably, motorcycles, cars and auto-rickshaws) on delays at intersections in mixed traffic in India is not well understood. Few attempts have been made to study the delays to vehicles at intersections under mixed traffic conditions (Popat *et al.* 1989; Agarwal *et al.* 1994) However, the study of impact of composition on delays at intersections under mixed traffic has not received sufficient attention and remains to be better understood. There are limited studies on behavior of motorcycles under mixed traffic conditions (Haque *et al.* 2008; Rongviriyapanich *et al.* 2010; Vien *et al*. 2008; Linh *et al.* 2010; Lee *et al.* 2012; Minh *et al.* 2012; Lee 2008). However, there are no studies on evaluation of ESSM on delays at intersections under mixed traffic conditions.

3.0 DEVELOPMENT OF SIMULATION MODEL

The traffic on Indian roads is highly heterogeneous, comprising vehicles of wide ranging static and dynamic characteristics. This type of traffic is characterized by lack of queue and lane disciplines (lane-less movement). The existing simulation model developed by Gowri *et al.* (2009) was modified to facilitate simulating traffic flow more realistically in a signalized intersection under mixed traffic conditions. The seepage of motorcycles to the front of queue are incorporated in the developed model. Further, the model was modified to facilitate simulating traffic flow with Exclusive Stopping Space for Motorcycle. For the purpose of simulation, the entire road space is considered as a single unit and the vehicles are represented as rectangular blocks on the road space. The model was developed in C++ language using Object

Oriented Programming (OOP) concepts. The genera flowchart of the simulation model is given in Fig. 3. The main parts of the traffic simulation model include data input and processing, generation of vehicles according to specified characteristics, placement and movement of vehicles (updating positions according to overtaking and car-following logics), accumulation and dissipation of vehicles and processing of output for individual vehicles as well as for traffic stream. The following logics were incorporated in the existing model.

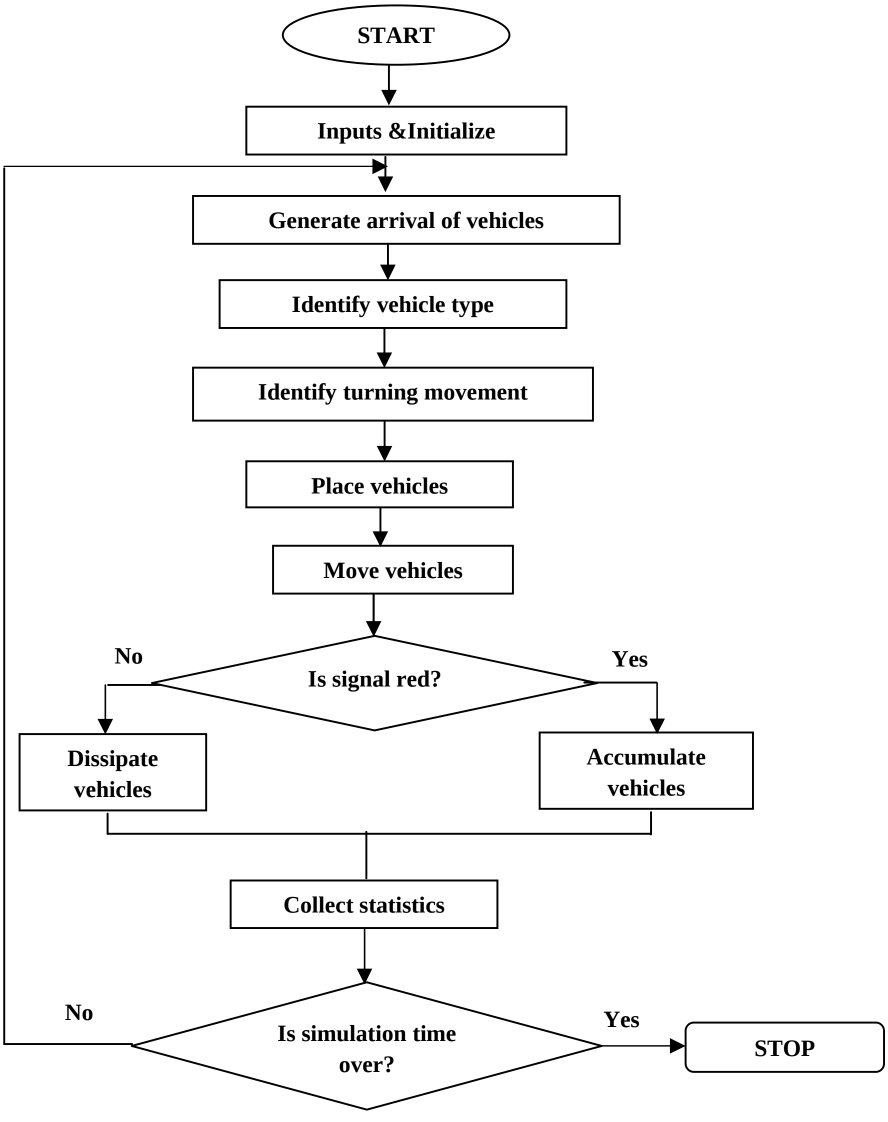


FIGURE 3 Framework for Simulation Model

3.1 Vehicle Generation
At the beginning of a simulation run, the road space is empty. Then the vehicles are generated at the starting point of the simulation road stretch. Once a vehicle is generated, the type of the vehicle (two-wheeler, car, auto-rickshaw, LCV, bus and truck) and turning movement (left, straight or right) are identified based on the observed composition of traffic and turning movement, respectively. The generated vehicle is assigned a free speed. The speed of vehicles on simulation road stretch is based on two assumptions: (a) vehicle speeds will not be allowed to exceed their free speeds in the entire stretch, and (b) the vehicles are entering the simulation stretch at their free speeds. The free speeds of vehicles follow normal distribution.

3.2 Vehicle Placement
Vehicle placement at mid-block sections is based on availability of transverse and longitudinal spaces. Motorized vehicles can move more freely and faster nearer to the median. So, they are placed beginning from the right edge (median edge) (in India, the traffic moves on the left side of the road). Longitudinal and transverse spacings of vehicles are determined based on their current speeds. The motorized vehicle looks for longitudinal and transverse spaces along the width of road from right edge to left edge of the road stretch. If spaces are sufficient, subject vehicle will be placed on the road stretch. If spaces are insufficient, it reduces its speed to that of its leader (car following rule). Again, similar checks for spaces are made, beginning from right most edge.

3.3 Vehicle Movement
In this simulation model, vehicle accelerates up to its free speed if there is no slow vehicle in front of it. The position of vehicle is updated based on equations of motion. When there is a slow moving vehicle in front of the subject vehicle, overtaking logic is invoked. During this stage, the subject vehicle (fast moving vehicle) checks for the free longitudinal and transverse spacings available on the right and left sides of the vehicle in front (slow moving vehicle). If spaces are adequate on the right side, right overtaking is performed; if not, the overtaking vehicle looks for availability of such spaces on the left side, and if available, left overtaking is performed. The time taken for this lateral motion depends on the current vehicle speed, type of the vehicle and its maximum acceleration rate. If spacings are inadequate on both sides, overtaking is not performed and car following logic is involved. In the car following logic, the speed of the following vehicle is reduced to that of the lead vehicle, maintaining a safe spacing from it.

3.4 Vehicle Accumulation
When the signal changes to red, the vehicles arriving near the intersection accumulate on the road based on the availability of spacings and type of turning movement. Logic used in the accumulation process is that vehicles try to occupy a position as closer to the stop line as possible. When the status of the signal is red, the vehicle will decelerate and come to stop. All the vehicles form queues behind the stop line based on their direction of movement. For example, the left turning vehicles form queue on the left side of the road. During each red phase of signal, all the vehicles accumulate on the intersection approach.

Since mixed traffic has no lane discipline, left turning, straight through and right turning vehicles accumulate on the approach haphazardly. Traffic simulation model requires accumulation data of vehicles as necessary input. For this purpose, traffic data collected at the case study intersection was used. The traffic movements during each red phase for peak period (30 minutes) ofthree consecutive days were analyzed to extract vehicle accumulation data. The x-and y-coordinates of the left and right edges of the vehicle were found out from the frames of the video data. Type of vehicle, type of turning movement, left coordinate, right coordinate, block number and grid number are noted down. Totally, 700 data points were obtained from one and half hour peak period. The data was analyzed using a MATLAB code. The conversion factors were applied to each data point to obtain the ground coordinates.

The cumulative frequency distribution curves were plotted by analyzing the data points for each type of movement (left, straight and right turning vehicles). The 85th percentile values from the cumulative frequency distribution curves are considered as the range of accumulation of each type of movement. Left turning vehicles accumulate from 0 m to 3.2 m. Straight through vehicles occupy from 0 to 5.2 m and right turning vehicles accumulate from 4.2 to 8.2 m. These vehicle accumulation values are given as inputs to the traffic simulation model to simulate the vehicle behavior at stopped condition during red signal phase.

3.5 Vehicle Processing at Dissipation

If the signal turns green, vehicles waiting at the intersection approach start dissipating after the reaction time. Initially, the current speed of all the accumulated vehicles is zero. Three manoeuvres are possible for individual vehicles when the vehicles clear the intersection area:

1. The leading vehicle may be able to accelerate freely up to its desired speed when there are no vehicles in front. These vehicles are termed as free movers in the simulation model.
2. The vehicle may follow a slow moving vehicle, with relatively lesser speed and acceleration values. Then, the vehicle is allowed to overtake the slow vehicle in front, if space is available. These vehicles are termed as overtakers.
3. If the subject vehicle may not be able to overtake because of insufficient free space; the vehicle will then simply follow the vehicles in front. Then the subject vehicle is termed as follower.

3.6 Seepage of Motorcycles to Fronts of Queues

At the case study intersection, 70% of all the vehicles are motorcycles. They reduce the speed of other modes and make the traffic more congested due to their size and behavior. They creep up slowly to the front of the queue when the signal is red, and impede traffic flow by disturbing the start of other vehicles behind. The maximum creeping speed used in the model was 10 km/h (Oketch 2000).

3.7 Simulation of Traffic Flow on Exclusive Stopping Space for Motorcycles (ESSM)

The program was modified for simulating the traffic flow on ESSM near the stop line. When the signal is in red phase, the motorcycles only can occupy ESSM and the remaining classes of vehicles are to stop before the ESSM space. Further, if spaces are available between larger vehicles, motorcycles will creep through spaces between these vehicles and try to reach the ESSM near stop line during red phase.

4.0 DATA COLLECTION AND EXTRACTION

In order to study the vehicle behavior under mixed traffic conditions, videographic survey of a signalized intersection at Ashok Nagar in Chennai city was conducted. This intersection has major approaches of 8.2 m (26.9 feet) road width and minor road approaches of 7.5 m (24.6 feet) road width. In this intersection, a total of nine hours (2-hour peak periods and1-hour off peak periods on three consecutive weekdays) of video recording was carried out from vantage points.

To reduce errors due to parallax effect of cameras, virtual gridlines overlaid on the video images were used. The approach road width of 8.2 m was divided into 8 grids of 1 m each, except the leftmost grid which is 1.2 m and length was divided into 4 blocks of 5 m each. Corresponding to these reference points on the ground, gridlines were overlaid on the video images using video editing and graphics software (Fig.4). Knowing distances on the ground and corresponding coordinates on the screen, conversion factors (screen to real) were worked out. The variations in x-and y-factors for different blocks are due to camera height and angle vis-à-vis the location of the block. These conversion factors reduce the parallax effect and are hence useful in assessing various accumulations during red signal phase. Video image processing software was used to extract data from the video. It extracts video images into frames where 1 second video data is converted into 25 frames. It was used to determine the screen coordinates of vehicle positions by manually viewing the individual frames. Each maneuver of vehicle was analyzed in detail and free speeds of vehicles, vehicle accumulation, control delay, deceleration, acceleration rate at dissipation, longitudinal spacing, etc., were extracted using frames.

5.0 MODEL CALIBRATION AND VALIDATION

To provide empirical support to test the concepts in this simulation work, a field study was conducted to determine the queue characteristics and traffic-dispersal patterns of mixed traffic. Data which are required as model parameters include the type of headway distribution, free speed characteristics of each type of vehicle, acceleration/deceleration characteristics of different types of vehicles, longitudinal spacing and vehicle accumulation during stopped condition.

The input parameters for simulation model, such as traffic volume, vehicle composition and proportion of turning movements were extracted from the video data. Total traffic volume at the intersection approach was 4000 vehicles/hour. Fig. 5 shows the vehicular composition at the major approach of the intersection and signal timings. Motorcycles comprised 70% of the total traffic volume on the study approach. Straight through, right turning and left turning vehicles comprised 75%, 18% and 7% of total vehicles, respectively.

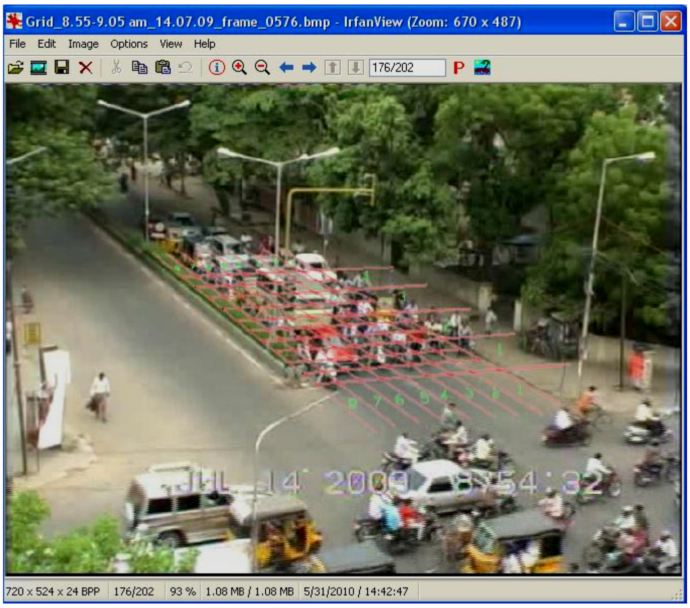
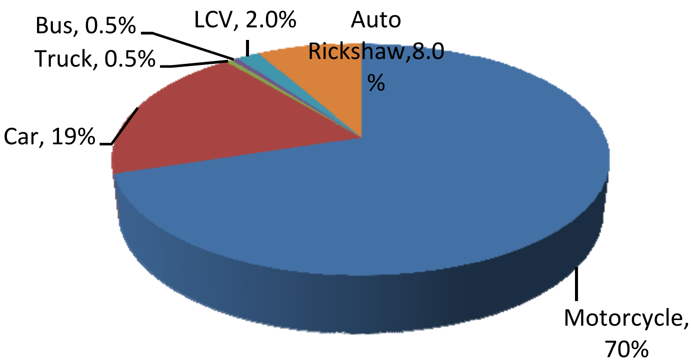


FIGURE 4 Gridlines overlaid on the video

Ability of the model to predict the traffic behavior of vehicles on the link of the intersection was examined with the help of data on control delay. The control delay for each vehicle type was obtained from field and simulation model for one hour peak period. Since locating cameras at vantage points had some limitations and restrictions in this study due to site conditions, a different methodology was adopted to estimate the control delay (different from conventional control delay). Table 1 shows the comparison of simulated and observed values of control delay for a volume level of 4000 vehicles per hour on each major approach. Control delay of Bus, LCV and Truck were combined as control delay of Heavy Vehicles (HV). The percentage of error between observed and simulated delay is less than 15% for all the vehicle types, which indicates that the model is reasonably replicating the field conditions. These values are acceptable and conform to the limits (15%) as proposed by Mathew and Radhakrishnan (2010) and Dowling *et al.* (2004).



Phase	Interval (s)
Red	70
Green	64
Amber	4
Cycle time	138

FIGURE 5 Vehicular Compositions and Observed Signal Timings at the Intersection

TABLE 1 Comparison of Observed and Simulated Control Delay

Vehicle Type	Control Delay (s/veh)		% of error
	Field (Average)	Model (Average)	
Motorcycles	46.0	52.0	11.5
Cars	40.0	50.0	12.0
Auto-rickshaws	40.0	50.0	12.0
Heavy Vehicles	45.0	52.0	13.5

6.0 MODEL APPLICATION - EXCLUSIVE STOPPING SPACE FOR MOTORCYCLES (ESSM)

Mixed traffic with high composition of motorcycles is a common situation in most of the urban roads in Chennai City, India. Motorcycles always try to get in front of queue during the red phase in order to clear the intersection more quickly as soon as the signal turns to green. Therefore, the concept of ESSM is conceived to give the motorcycle an opportunity to get in front of other vehicles on the approach. During the red phase, motorcycles will slowly move up and get in front of other vehicles that are waiting at the stop-line. Fig.6 illustrates the provision of ESSM near the stop line on both the major approaches of the case study intersection.

If motorcycle composition is dominant at an intersection, the intersection control parameters such as control delay, dissipation of vehicles and queue length depend on dimension of the vehicles, acceleration characteristics, filtration of motorcycles and other traffic dynamics and physical characteristics. In such a condition, when the signal is in red phase and if the front row is occupied by other than motorcycles such as cars, trucks and LCVs, the delay at the intersection increases. Also, dissipation of vehicles per cycle is reduced due to their low acceleration characteristics and they also obstruct the motorcycle flow at the intersection. So, if the motorcycle composition is dominant, ESSM can be provided near the stop line of intersection. When the signal is in red, only motorcycles should occupy that space and the remaining types of vehicles should stop before the ESSM. This facilitates the motorcycles to dissipate faster when the signal turns to green, thereby reducing the delay to motorcycles; also, the overall delay at the intersection reduces.

6.1 Influencing Parameters and Assumed Values for Sensitivity Analysis

The case study intersection approach has total volume of 4000 veh/h/major approach. The proportion of left- and right-turning vehicles is 7% and 18%, respectively, at the major approaches of the intersection. The width of the intersection approaches (major) is 8.2 m. The following parameters are considered as relevant factors. The values assumed for these parameters for the simulation runs are noted below:

- Total approach volume on each of the major approaches is varied from 500 veh/h to 4000 veh/h. The total volume on each of the minor approaches is taken as 500 veh/h.
- Motorcycle composition was varied from 19% to 70%.
- Length of ESSM on both approaches is varied from 2 m to 6 m in increments of 2 m.
- Duration of red phase on both the approaches is taken as 51% of total cycle time (field data).
- Total cycle time of the signal is taken as 138 s based on field data.

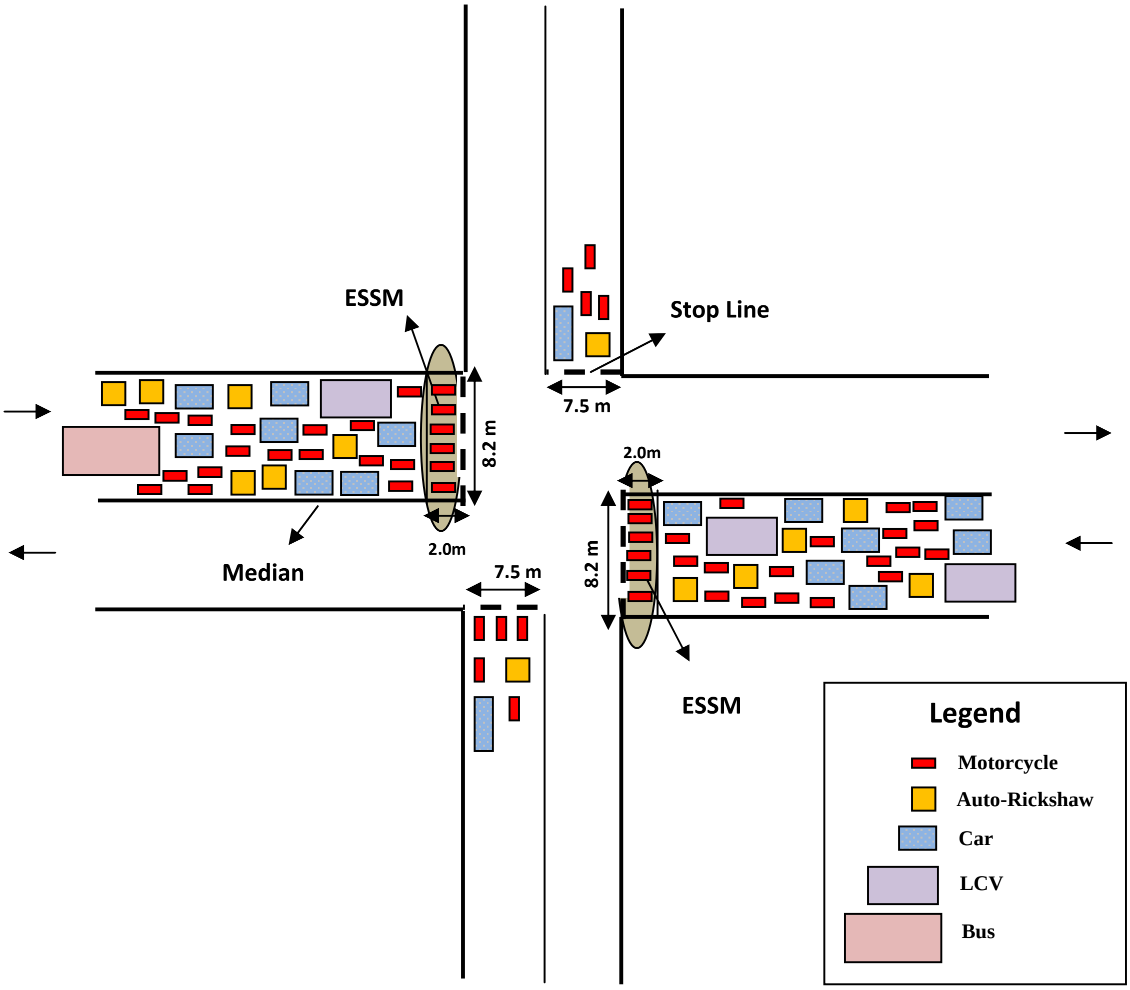


FIGURE 6 Schematic Layout of ESSM Provided Near the Stop Line on the Major Approaches of the Intersection

For this analysis, the traffic composition of the approaches shown in Table 2 is considered. Each scenario was examined in two sets of simulation modeling runs: one with and one without an ESSM. In each case, three simulation runs were carried out (using three seeds) and the average values of control delays are taken. Simulation runs were performed for 225 scenarios with ESSM and 60 scenarios without it, for a total of 285 scenario runs (for each major approach). Each simulation run represented one hour of traffic flow.

TABLE 2 Traffic Compositions used for ESSM Analysis

Scenario No.	Vehicle Composition (%)					
	Motorcycle	Car	Bus	Truck	LCV	Auto-Rickshaw
1	70	19	0.54	0.49	1.71	8.13
2	44	45	0.54	0.49	1.71	8.13
3	19	70	0.54	0.49	1.71	8.13

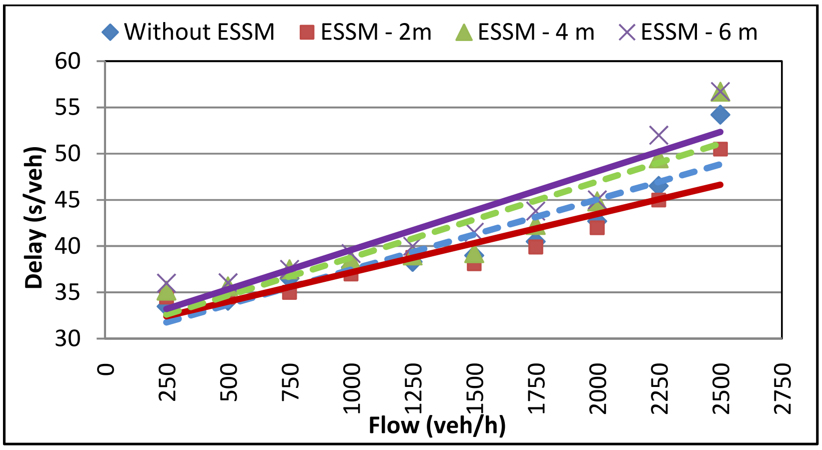
6.2 Results and Discussion

Figures 7 show the average control delay values to all vehicles (with and without ESSM), respectively on major approach 1. Generally, when the motorcycle composition is lesser, delay to vehicles is higher in the case of absence of ESSM. This may be due to lower dissipation rate of cars and lesser filtering of motorcycles. If the motorcycle composition is 19% (car 70%) and volume is less than 1000 veh/h, 2 m ESSM is not beneficial. This may be due to less number of motorcycles at low volume levels. If the volume level increases, 2 m ESSM is beneficial. For longer ESSM (4 m and 6 m), it is not beneficial for all volume levels (Fig. 7a); since motorcycle proportions are very less, ESSM space is not properly utilized, which results in increase in delay to all vehicles.

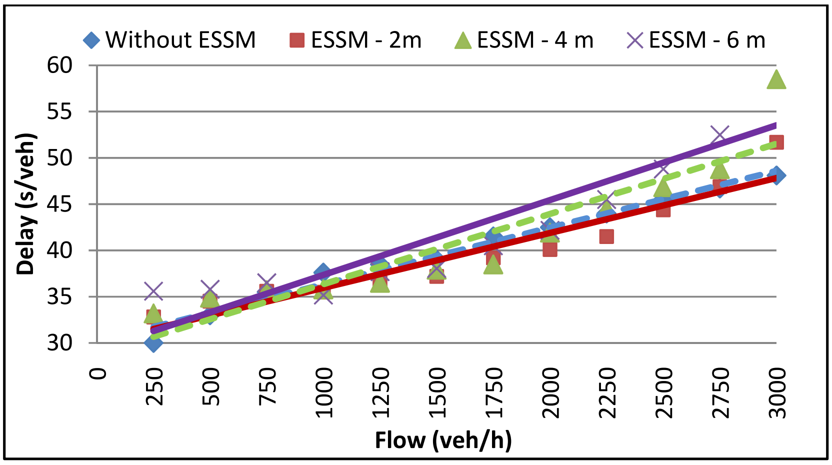
When the motorcycle composition is 44% and car composition is 45%, 2 m ESSM is beneficial at higher volume levels. The breakeven point starts at 750 veh/h. 4 m ESSM is beneficial up to 750 veh/h and when the volume level increases, it is not beneficial due to under utilization of ESSM. This shows that when the motorcycle composition increases, benefits of ESSM are increasing. 6 m ESSM has disbenefits at all volume levels (Fig. 7b). This may be due to underutilization of ESSM.

If the motorcycle composition is 70% (car 19%), 2 m ESSM is beneficial for all volume levels. When the motorcycle composition is dominant, ESSM yields higher benefits for shorter ESSM. The ESSM is properly utilized at all volume levels. 4 m ESSM has benefits at higher volume levels. The breakeven point starts at 1500 veh/h. This shows that only at higher volume levels, 4 m is beneficial and at lower volume levels it is underutilized (Fig 7c). 6 m ESSM has disbenefits at all volume levels due to wastage of ESSM space.

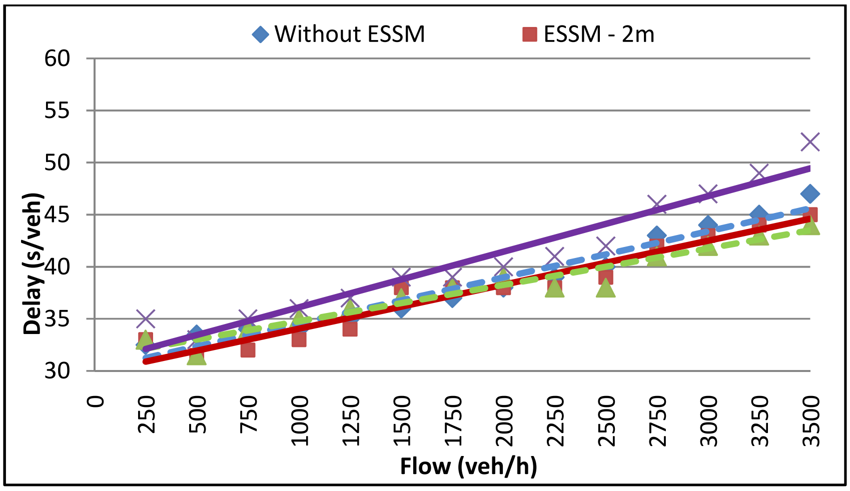
It can be generally concluded that when the motorcycle composition is dominant, ESSM yields beneficial results at higher volume levels, i.e., lesser delays (compared with no ESSM). When the proportion of cars is dominant, ESSM yields disbenefits, in general, at higher volume levels. Also, it can be noted that when the motorcycle composition is higher, capacity is also higher and delays to vehicles are lesser. This may be due to higher dissipation rate of motorcycles due to its high maneuverability, filtering and parallel movements.



a) 19% Motorcycles



b) 44% Motorcycles



c) 70% Motorcycles

FIGURE 7 Comparison of Control Delays to all vehicles with and without ESSM

Further scenario analysis need to be conducted to suggest guidelines on the optimal lengths of ESSM. The above insights can lead to better traffic management and control strategies at signalized intersections under mixed traffic conditions. However, more case studies and further scenario analysis need to be conducted to generalize the results. These may be taken as scope for future work.

7.0 CONCLUSIONS

In many of the South Asian countries like India, composition of motorcycles on urban roads (particularly in Chennai city) are high. Due to high maneuverability, motorcycles will often attempt to seep through queuing vehicles (in red phase) to get to the front of the queue; they will then depart together within a very short period of time once the traffic signal turns green. Special treatment at intersections is given to motorcycles to facilitate their clearance from the intersection quickly, and thereby reduce delays to other vehicles. In this paper, a microscopic traffic simulation model for signalized intersection under mixed traffic conditions, which is implemented in C++ language using Object Oriented Programming (OOP), was used to simulate traffic flow near an intersection with and without Exclusive Stopping Space for Motorcycles (ESSM) near the stop line. The benefits are studied by varying the vehicular composition, traffic volume and ESSM lengths. The key conclusions arising out of this study are:

1. When the motorcycle composition is dominant (70%), ESSM yields beneficial results (lesser delays) at higher volume levels. This holds true for control delays of all vehicles as well as motorcycles.
2. When the proportion of cars (45%) and motorcycles (44%) is almost equal, ESSM is beneficial at moderate volume levels for all lengths of ESSM.
3. When the proportion of cars is dominant (70%), ESSM yields disbenefits, in general, at higher volume levels and longer ESSM.

More case studies and further scenario analysis need to be conducted to generalize the benefits of ESSM. The model can be valuable to field traffic engineers in implementing traffic control/management measures for better utilization of intersection space and smoother flow of traffic.

8.0 ACKNOWLEGEMENTS

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