COMPUTER AIDED MODELING OF MIXED TRAFFIC FLOW AT URBAN UNCONTROLLED INTERSECTIONS

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ABSTRACT

Modeling of road traffic at the intersections will enable comprehensive study of the traffic flow characteristics, which in turn, will enable better design and operation of the intersections. Uncontrolled at-grade road intersections have no traffic control devices and the vehicles maneuver through such intersections by self control. These intersections are more common in developing countries like India. This study pertains to India, where the road-traffic is highly heterogeneous. Hence, a systematic study of the mixed traffic flow through these intersections is necessary to attempt improvement measures at the intersections. Here, the traffic flow at urban uncontrolled intersections has been modeled using simulation technique. The coding for the simulation was written in C++ programming language. The developed model, when validated with field observed traffic data, was found to replicate the field condition satisfactorily. The validated model was then applied to estimate the delay to traffic at various traffic-volume levels, which will serve as the basis for taking up of appropriate traffic improvement measures.

KEY WORDS

Road traffic, Uncontrolled intersection, Heterogeneity, Modeling, Simulation.

INTRODUCTION

At-grade road intersections with no traffic control system, where traffic moves by self-control are known as uncontrolled intersections. These intersections are common in developing countries like India. At uncontrolled intersections, in the absence of indication of specific time intervals to each of the streams of traffic to cross the intersection, the drivers look for gaps in the traffic streams and cross the intersection. Vehicles approaching uncontrolled intersections through the connected roads, on arrival, assume equal right to enter the intersection, and this has increased the probability of occurrence of conflict between vehicles in the intersection area. Moreover, in India, the traffic is highly heterogeneous comprising different types of vehicles with widely varying size, shape, speed and other maneuvering characteristics. All these have made the traffic situation pariticularly at urban uncontrolled intersections, highly complex warranting a systematic approach to study the

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traffic. The use of simulation technique in modeling traffic flow, has been facilitated by the widespread availability of high speed electronic computers which make possible the replication of incredible number of events of a process in a very short time. This paper is concerned with the development of a micro simulation model of mixed traffic flow through urban uncontrolled intersections with due consideration to the roadway and traffic conditions prevailing in India.

LITERATURE REVIEW

The review of literature on the theme of the study showed that most of the research works done on the subject matter are all related to homogeneous traffic flow at stop controlled intersections. A few studies done in developing countries such as India, where uncontrolled intersections exist, however, are found to be closely related to the present study. Raghavachari *et al.* (1993) studied the interaction of pedestrians and vehicles in terms of delay suffered at urban uncontrolled intersections under mixed traffic-flow conditions and developed a model named, PEDVIM for simulating pedestrian movements at these intersections. Agarwal *et al.* (1994) developed a simulation model of heterogeneous traffic flow at a four-legged, right–angled, uncontrolled intersection. This model was used to determine the total delay and queue length on all the approaches. Rengaraju and Trinadha Rao (1995) attempted to identify suitable probability distributions for vehicle arrivals at uncontrolled intersections under mixed traffic conditions. Arasan and Trinadha Rao (2003) developed a model to estimate the delay to mixed traffic at urban uncontrolled intersections. The model was found to be statistically and logically sound, indicating good potential for direct application for estimating delay, under conditions similar to the case considered for the study. Ashalatha et al. (2005) attempted to study the driver behavior at an uncontrolled T-junction in mixed traffic condition. From the study, it has been found that the minimum acceptable gap increases with increase in the dimensions of a vehicle. It is also found that shifted exponential distribution is a better distribution to fit gap acceptance at low traffic volume levels. The cited studies reveal that these were location specific and had several limitations. Also, these studies did not take into consideration the absence of lane and queue discipline under heterogeneous traffic conditions prevailing in developing countries such as India. Hence, there is a need to comprehensively model mixed traffic flow through uncontrolled intersections to accurately replicate the field conditions and study the flow characteristics.

SIMULATION FRAMEWORK

The different types of vehicles on the city roads of India can be grouped into nine types as (i) Bus, (ii) Truck, (iii) Light Commercial Vehicle (LCV) - large passenger vans and small trucks, (iv) Cars - cars, jeeps and small passenger vans, (v) Motorized Three-Wheeler (M.Th.W) - three wheeled motorized vehicles to carry a maximum of three passengers or small quantities of goods, (vi) Motorized Two-Wheeler (MTW) - motor cycles, scooters and mopeds, (vii) Bicycle, (viii) Tricycle – three wheeled pedal-type vehicle to carry a maximum of two passengers or small quantities of goods, (ix) Animal Drawn Vehicles (A.D.V)–carts drawn by bullock/horse/camel. The smaller vehicles like motorized two-wheeler, and bicycle are predominant and these share the same road space (without segregation) with other larger vehicles. Hence, there is difficulty in imposing lane discipline under such conditions and the vehicles occupy any lateral position on the road depending on the availability of space at a particular instant.

In view of said characteristics of traffic, 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 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 area (uncontrolled intersection) is divided into five parts, namely, the four approach roads and the intersection area. Each of the parts have different origins with x and y axes considered along convenient directions (Fig.1). For each of the four approaches, an imaginary line across the road at the vehicle-placement section is taken as X-axis and the left curbside of the road at that section is taken as Y-axis. The intersection is considered as a common area for movement of vehicle from all the approaches. Hence, the positions of all the vehicles in the intersection area are represented with reference to a single origin O_5 with X and Y axes being as shown in Fig. 1. Once the front of a vehicle touches the edge of the intersection area, the vehicle is considered to have

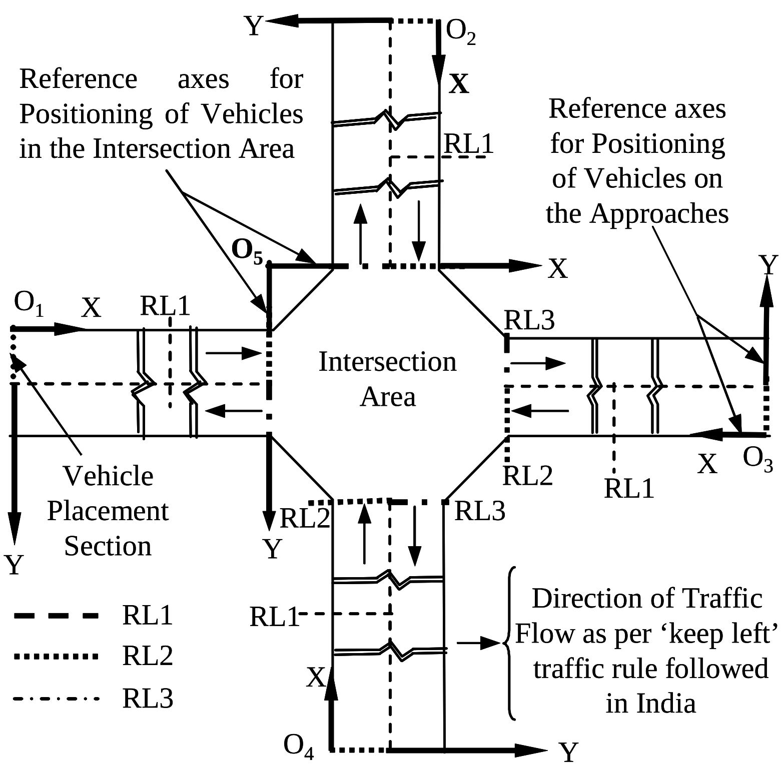

Figure 1: Reference Lines and Axes for Simulating Traffic

moved out of the approach and entered the intersection area. Then the x and y coordinates for the vehicle position will be fixed based on the reference axes with origin O_5, irrespective of the approach from which a vehicle is entering the intersection area. An imaginary line across the road at a section on the approach, wherefrom the maneuvering characteristics of vehicles approaching the intersection may be influenced by the intersection geometry, traffic condition at the intersection and the intended direction of movement of the subject vehicle, is taken as Reference Line 1 (RL1). An imaginary line across the road at a section on the approach, wherefrom the driver gets a clear view of the crossing roads to check for the location and speed of the approaching vehicles on the cross roads, is taken as the Reference Line 2 (RL2). An imaginary Line across the exit part of the intersection leg at a section, where from the vehicles leaving the intersection, will be free from the effect of the intersection, is taken as Reference Line 3 (RL3). This section, for the purpose of modeling, is the exit point for the vehicles leaving the intersection.

THE MAJOR STEPS

The three major steps considered in simulating the traffic flow in this case are: (1) Vehicle generation, which is related to the pattern of arrival of vehicles at the beginning of the simulation stretch, and their associated characteristics, (2) Vehicle placement, which will govern the process of admitting the vehicles into the system at the correct time and position on the road space and (3) Vehicle movement, which is concerned with the sequential updating of the position of all vehicles in the system during each scan interval.

VEHICLE GENERATION

The vehicle generation step involves generation of inter arrival times of vehicles, identifying the type of vehicle and the direction of movement, and assigning speed and other manoeuvring characteristics. Since arrival of vehicles is a random process, it is represented using random numbers in the simulation process. By knowing the statistical distribution which fits well the field observed headway of vehicles, vehicle arrivals can be generated theoretically by generating random numbers as per the chosen statistical distribution. The random numbers thus generated are then, converted, using suitable methods, (Banks et al. 2000), into random variates. Once a vehicle is generated as per the applicable theoretical distribution, the type of vehicle is identified based on the percentage composition of traffic and the turning movement of that particular vehicle is identified based on the percentage of the different directions of movement of that particular vehicle type from that particular approach.

Another random process associated with the vehicles is the free speed. As per the available literature, free speeds of vehicles generally follow Normal distribution. It is assumed for the purpose of modeling, that all vehicles enter the simulation road stretch, following Normal distribution, at their free speed, and during the simulation process, the vehicles will not exceed their assigned free speeds. Free speeds are assigned to generated vehicles by assigning random values through generation of random numbers as per Normal distribution and transforming the random numbers into Normal variates by Box-Muller-Transformation method (Banks et al. 2000).

VEHICLE PLACEMENT

As the mixed traffic on urban roads of India does not follow traffic lanes, there is a need, for the purpose of simulation, to represent the vehicles on the road space with dimensions. Vehicle placement implies placing these rectangular blocks (whose length and breadth represent, respectively, the average overall length and breadth of the different types of vehicles) at the start of the simulation stretch in a suitable position across the width and along the length of the road based on the longitudinal and lateral clearance requirements for the subject vehicle.

VEHICLE MOVEMENT

This deals with updating of positions of all the vehicles in the study stretch, sequentially, beginning with the exit end, using the formulated movement logic. The updation technique followed in this model is periodic scanning and the scan interval has been chosen as one second. Since vehicles do not follow lane, there is a need to give the minimum lateral gap between vehicles and the rate of increase of the gap as the speed increases, as input to the model. The lateral gap is the clear space between a side of the subject vehicle and the near sides of the adjacent vehicle. The lateral and longitudinal clearances between vehicles will be the minimum when they stop on the road space. Based on field observations, values of clearance share in lateral direction for each type of vehicle was arrived at. The values for the different types of vehicles are shown in columns (4, and 5) of Table 1. For example, at zero-speed condition, the lateral clearance between a Truck and a Car, when they stand side by side, will be equal to 0.4 + 0.3 = 0.7 m (refer column 4 of Table 1). The lateral clearance is assumed to increase linearly in direct proportion to the speeds of the vehicles to reach the maximum value (at 60 kmph) as indicated in column 5 of Table 1. Similarly, the minimum gap between the front of a bus and the back of a car in front will be (0.8+0.5) = 1.3 m (column 6 of Table 1). The acceleration rate of a vehicle will depend on the vehicle type and speed. The acceleration rates of the different types of vehicles for three different speed ranges are shown in columns (4), (5) and (6) of Table 2.

Table1: Overall Dimensions of and Spacing between the Different Categories of Vehicles

Type of Vehicle	Overall Dimension (m)		Minimum Lateral Clearance Share (m)		Minimum Longitudinal Clearance Share (m)
	Length	Breadth	Zero Speed	Speed $\geq$ 60 Kmph	
(1)	(2)	(3)	(4)	(5)	(6)
Bus	10.3	2.5	0.4	0.6	0.8
Truck	7.5	2.5	0.4	0.6	0.8
LCV	5.0	1.9	0.3	0.5	0.6
Car	4.2	1.7	0.3	0.5	0.5
M.Th.W.	2.6	1.4	0.2	0.3	0.3
M.T.W.	1.8	0.6	0.2	0.4	0.2
Tricycle	2.5	1.3	0.2	0.3	0.2
Bicycle	1.9	0.5	0.2	0.3	0.2
LCV: Light Commercial Vehicles; MTHW: Motorised Three-Wheelers; MTW: Motorised Two-Wheelers					

Table 2: Dynamic Characteristics of the Different Categories of Vehicles

Type of Vehicle (1)	Free Speed (kmph)		Acceleration Value at Various Speed Ranges (m/s^2)		
	Mean (2)	Standard Deviation (3)	Speed 0-20 kmph (4)	Speed 20- 40 kmph (5)	Speed Above 40 kmph (6)
Bus	34.06	3.87	0.89	0.45	0.33
Truck	32.83	4.82	0.79	0.45	0.33
LCV	34.23	4.44	0.82	0.60	0.35
Car	37.77	4.51	1.50	1.30	1.00
MThW	33.97	2.97	1.01	0.58	0.34
MTW	38.06	4.12	1.35	1.03	0.37
Tricycle	10.00	3.00	0.07	NA	NA
Bicycle	13.00	3.20	0.10	NA	NA
LCV: Light Commercial Vehicles; MThW: Motorised Three-Wheelers; MTW: Motorised Two-Wheelers; NA: Not Applicable					

COMPUTER PROGRAM

In this study, Turbo C++, which is an Object Oriented Programming (OOP) language, has been used for developing the program by taking advantage of its special features like, *data hiding*, *inheritance*, *virtual functions*, *overloading of functions*, *data structures*, etc., which make the coding relatively easier, and also help to minimize the length of the program. Also, the computer code is executed at a faster rate because of the flexibility provided by the language to the compiler. The computer program contains several functions, which fulfill the specific requirements of this study such as, animation, and other logical aspects. Coordinate system was used to represent all the physical features such as vehicles, intersection geometry, etc. The program contains a total of 9000 lines (codes). The major logical steps related to the working of the program are depicted in the flow diagram shown as Fig.2.

INPUT TO THE MODEL

The input file of the simulation program contains the following variables, which can be varied during model application: (i) Traffic volume in vehicles per hour, (ii) Traffic composition, (iii) Direction of movement of vehicles, (iv) Reaction time of drivers, (v) Length and width of approach roads, (vi) Total simulation time, (vii) Scan interval and (viii) Random number seed, which is to be changed for each simulation run. The built-in model parameters, which are included in the input file, are: (i) Parameter values of statistical distributions for headway generation, (ii) Overall dimensions of different types of vehicles, (iii) Maximum and minimum values of lateral clearances between vehicles, (iv) Minimum longitudinal clearance between vehicles, (v) Acceleration / deceleration characteristics of different types of vehicles, and (vi) Free speed of each category of vehicle.

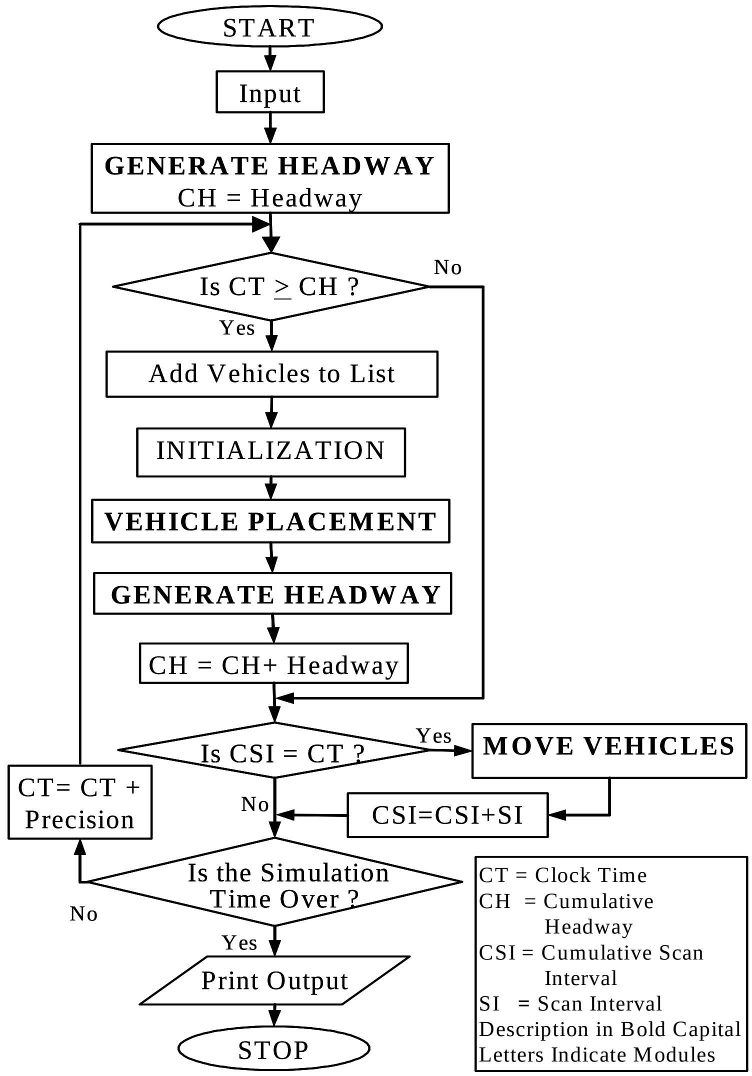

Figure 2: Simulation Framework for the Main Program

OUTPUT OF THE MODEL

The model gives two types of outputs namely, numerical values representing the various system parameters, and animation of the traffic flow showing the system state during simulation run. The final numerical, output obtained from the program, are: traffic volume, overall delay, stopped delay and average speed. The simulation model also has an animation module, which provides a graphical display of the movement of vehicles through the intersection. Fig.3 illustrates the snapshot of the animation of traffic flow through uncontrolled intersection.

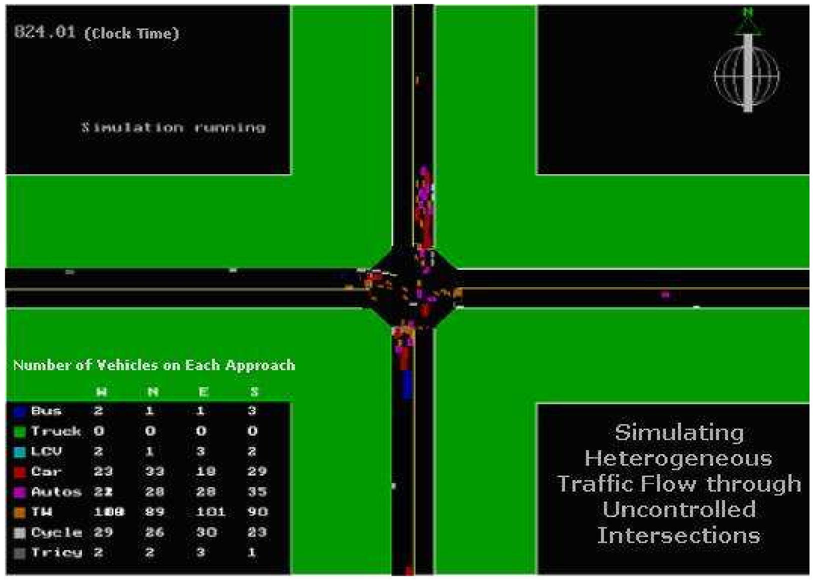

Figure 3: Snapshot of the Animation of Simulated Traffic Flow

FIELD DATA COLLECTION

The required traffic data for the study was collected by observing traffic flow through an uncontrolled intersection located in Ashok Nagar area in Chennai city, where the, 10th Avenue and 7th Avenue cross each other at right angles. Data on traffic volume, composition, interarrival time (headway) and free speeds of vehicles were collected at the intersection. The traffic composition at the intersection is shown in Fig. 4. The interarrival time of vehicles was found to fit the exponential distribution. The free speeds of vehicles were found to follow the Normal distribution.

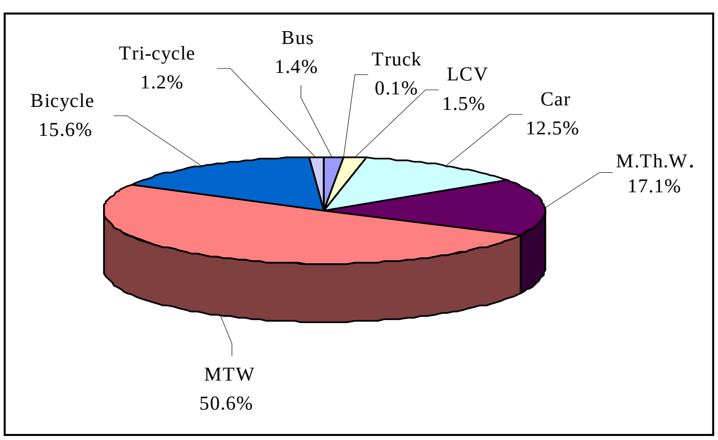

Figure 4: Composition of Traffic at the Study Intersection

MODEL VALIDATION

The developed simulation model was validated by checking whether the model is able to replicate the field traffic conditions. The necessary observed data were given as input to the simulation model and the analysis of the output was carried in Microsoft Excel work sheets. The simulation model was run three times, each time with different random number files, and the average of the three runs was taken as the final output for each input-data set. A comparison of observed and simulated vehicle arrivals on the approaches of the study intersection is furnished in Table 3. It can be seen from the Table that the observed and simulated values in respect of total number of vehicles, closely match with each other, indicating the validity of the model.

Table 3: Comparison of Observed and Simulated Vehicle Arrivals at the Study Intersection

Type of Vehicle	Number of Vehicles per hourr.											
	10th Avenue (East)			10th Avenue (West)			7th Avenue (North)			7th Avenue (South)		
(1)	Obs. (2)	Sim. (3)	Error (4)	Obs. (5)	Sim. (6)	Error (7)	Obs. (8)	Sim. (9)	Error (10)	Obs. (11)	Sim. (12)	Error (13)
Bus	10	10	0.0	27	25	7.4	23	22	4.3	0	0	0.0
Truck	0	0	0.0	0	0	0.0	0	0	0.0	5	6	-20.0
LCV	14	16	-14.3	25	26	-4.0	17	19	-11.8	11	12	-9.1
Car	142	134	5.6	127	134	-5.5	169	172	-1.8	111	103	7.2
MThW	183	193	-5.5	208	201	3.4	220	225	-2.3	136	137	-0.7
MTW	556	557	-0.2	551	539	2.2	609	599	1.6	506	529	-4.5
Bicycle	143	156	-9.1	180	183	-1.7	219	205	6.4	140	146	-4.3
Tricycle	10	8	20.0	11	10	9.1	23	23	0.0	8	7	12.5
Total	1058	1074	-1.5	1129	1118	1.0	1280	1265	1.2	917	940	-2.5

MODEL APPLICATION

As a demonstration of the usefulness of the model, the model was applied to estimate the delay caused to vehicles at the intersection. Both the stopped and overall delays were estimated for one hour to get a representative value of the delays. The variation of the average overall and stopped delays to traffic, over the volume of traffic, for an uncontrolled intersection with 7.5m wide approaches, considered as example, is depicted in Fig. 5. It can be seen that the delays increase steeply after a traffic volume level of 1400 PCU per hour indicating the need for traffic control measure beyond that volume level.

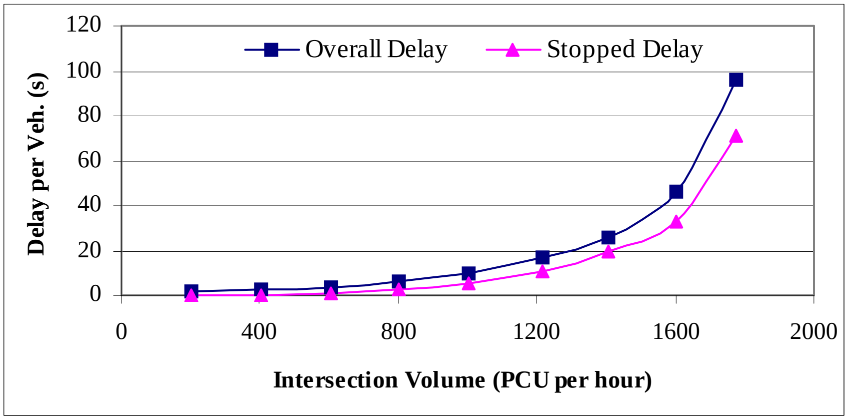

Figure 5: Overall and Stopped Delay to Vehicles

CONCLUSIONS

The following are the important conclusion of this study: (1) As the first step in the study, an appropriate simulation framework for modeling the non-lane based heterogeneous traffic prevalent on urban roads of India, with specific reference to uncontrolled intersections, has been developed. Based on the above framework a computer program package was developed using C++ programming language. (2) The developed simulation model, when validated based on field observed data was found to replicate the field traffic flow to a satisfactory extent, which indicates the validity of the model and (3) As an illustration of the usefulness of the model, the model was applied to estimate the average delay to traffic at various traffic volume levels and this information can be used to determine the level of service offered and the volume level at which traffic control is to be introduced at uncontrolled intersections.

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