



Evaluation of Intersection Traffic Control Measures through Simulation

Gowri Asaithambi¹ · R. Sivanandan²

Received: 20 July 2012 / Accepted: 3 September 2015 / Published online: 5 October 2015
© The Institution of Engineers (India) 2015

Abstract Modeling traffic flow is stochastic in nature due to randomness in variables such as vehicle arrivals and speeds. Due to this and due to complex vehicular interactions and their manoeuvres, it is extremely difficult to model the traffic flow through analytical methods. To study this type of complex traffic system and vehicle interactions, simulation is considered as an effective tool. Application of homogeneous traffic models to heterogeneous traffic may not be able to capture the complex manoeuvres and interactions in such flows. Hence, a microscopic simulation model for heterogeneous traffic is developed using object oriented concepts. This simulation model acts as a tool for evaluating various control measures at signalized intersections. The present study focuses on the evaluation of Right Turn Lane (RTL) and Channelised Left Turn Lane (CLTL). A sensitivity analysis was performed to evaluate RTL and CLTL by varying the approach volumes, turn proportions and turn lane lengths. RTL is found to be advantageous only up to certain approach volumes and right-turn proportions, beyond which it is counter-productive. CLTL is found to be advantageous for lower approach volumes for all turn proportions, signifying the benefits of CLTL. It is counter-productive for higher approach volume and lower turn proportions. This study pinpoints the break-even points for various scenarios. The developed simulation model can be used as an appropriate intersection lane control tool for enhancing the efficiency of flow at

intersections. This model can also be employed for scenario analysis and can be valuable to field traffic engineers in implementing vehicle-type based and lane-based traffic control measures.

Keywords Signalised intersection · Simulation · Object oriented programming · Turn lanes

Introduction

Signalised intersections are vital nodal points on urban road networks. The performance of urban road networks is greatly influenced by the effectiveness with which the traffic signals operate. Homogeneous traffic consists of a stream of identical vehicles (mostly cars) following lane discipline at these intersections. But in heterogeneous traffic conditions, mix-up of vehicles is high and vehicles do not follow ordered queue and lane discipline. Moreover, vehicular flows making left, through and right turning movements seek to occupy the same physical space as close to the stop line as possible. These result in conflicts and vehicles accumulate at the intersection approaches haphazardly, leading to congestion, delays, and reduction in intersection capacity. Due to heterogeneity of traffic and unique driver behavior, turning vehicles block the through vehicles by occupying their road space in the approach and vice versa, leading to delays. These issues make the understanding and modeling of heterogeneous flow at intersections very difficult.

Modeling traffic flow is stochastic in nature due to randomness in variables such as vehicle arrivals and speeds. Due to this and due to complex vehicular interactions and their manoeuvres, it is extremely difficult to model the traffic flow through analytical methods. Based

✉ Gowri Asaithambi
gowri_iitm@yahoo.co.in

¹ Department of Civil Engineering, National Institute of Technology Karnataka, Surathkal, Mangalore, India

² Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, India

on the past research, simulation technique is found to be appropriate for modeling traffic flow [1, 2]. Commercial software such as VISSIM, PARAMICS, NETSIM, FRE-SIM, INTRAS, CORSIM and INTELSIM have been developed to simulate homogeneous traffic characteristics [3–5]. These software are not believed to be appropriate for studying heterogeneous traffic, due to wide variations in flow characteristics of heterogeneous traffic vis-à-vis homogeneous traffic. Though comprehensive commercial software is not yet available for studying heterogeneous traffic, attempts have been made by researchers to model various aspects of such traffic. A review of the literature shows that only limited studies have been done to develop a simulation model for intersections under heterogeneous traffic conditions [6–14].

The present study focuses on the development of microscopic traffic simulation model for signalised intersections under heterogeneous traffic conditions. The model was also used to test the efficacy of turn lanes such as Channelised Left Turn Lane (CLTL) and Right Turn Lane (RTL).

Development of Simulation Model

A microscopic traffic simulation model was developed using Object Oriented Programming (OOP) concepts and implemented in C++ programming language [15]. In this model, the entire road space is considered (rather than individual lanes), since vehicles do not follow lane discipline. The logics incorporated in the simulation model such as vehicle generation, vehicle placement, vehicle movement, vehicle accumulation and vehicle dissipation, and vehicle movement at turn lanes are explained in the following sub sections.

Vehicle Generation

At the beginning of a simulation run, the road space is empty. Vehicles are generated at the starting point of the simulation road stretch based on semi parametric distribution. The generated vehicle is assigned a vehicle type and turning movement; it is also assigned a free speed. The free speeds of vehicles follow normal distribution. The standard normal deviates are generated using Box-Muller transformation method by using the equation:

$$Z = \sqrt{-2 \ln R_1} \times \cos(2\pi R_2) \quad (1)$$

where Z = standard normal deviate; R_1, R_2 = random numbers.

The free speed of each vehicle category can be obtained as

$$u_{fi} = \mu_i + \sigma_i Z \quad (2)$$

where u_{fi} = free speed of the vehicle category i (Two-wheeler, Car, Bus, etc.), μ_i = mean speed of vehicle category i , σ_i = standard deviation of speed of vehicle category i .

The simulation program developed for this study uses different random-number streams for the generation of vehicle arrivals, identification of vehicle type and turning movement and assigning free speed.

Vehicle Placement

Vehicle placement at mid-block sections is based on availability of transverse and longitudinal spaces. Figure 1 presents the methodology for vehicle placement. Vehicles can move more freely and faster nearer to the median. So, they are placed from beginning from the right edge of the road stretch. Longitudinal and transverse spacing of vehicles are determined based on their current speeds. The vehicle looks for longitudinal and transverse spaces in right most section of the road stretch. If the available transverse and longitudinal spacing are sufficient, the vehicle is placed on the rightmost location, leaving the specified clearance from the right edge. If either of them are inadequate, the available longitudinal and transverse spacing with respect to the next-to-be-considered vehicle on the left side, are compared with the respective values required for the entering vehicle to enable its placement behind it. Thus, vehicles check the longitudinal and lateral spacing progressively from right edge to left edge of the road stretch. If such spaces are insufficient, subject vehicle reduces its speed to that of its leader (car following rule). Again, similar checks for spaces are made, beginning from right most edge.

Vehicle Movement

The general methodology for vehicle movement is illustrated in Fig. 2. 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 the equations of motion.

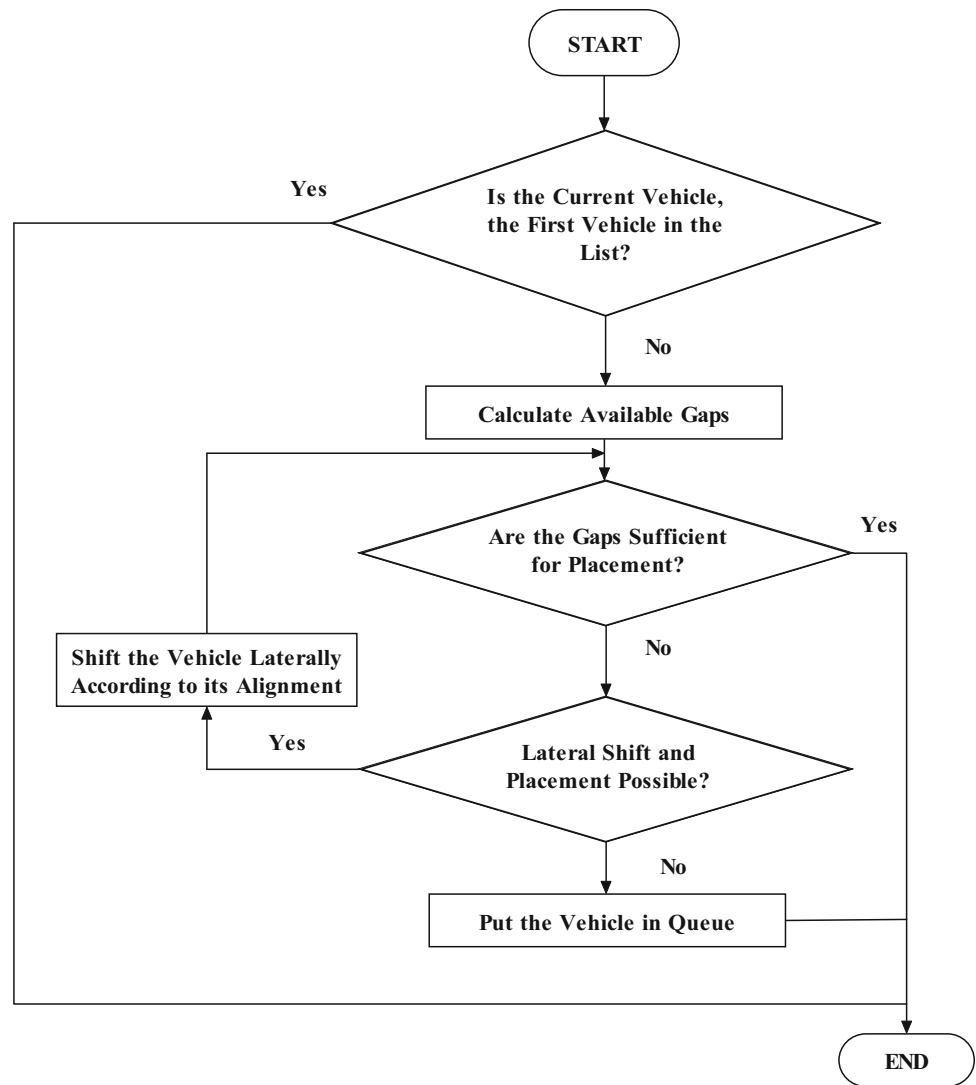
$$S = ut + \frac{1}{2}at^2 \quad (3)$$

and

$$v = u + at \quad (4)$$

where S = distance moved by the vehicle, m, u = initial speed of the vehicle, m/s, a = acceleration of the vehicle, m/s^2 , t = scan interval, s, v = speed of the vehicle, m/s at the end of the scan interval.

Fig. 1 Methodology for placement of a vehicle



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). An overtaking manoeuvre is performed, if the longitudinal and lateral spacing are available. If transverse spacing is inadequate on both sides, overtaking is not performed and car following logic is invoked.

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.

Figure 3 illustrates the methodology for vehicle accumulation. The vehicles were placed on the road to occupy logical positions starting from the left side of the road except the right turning vehicles. After reaching the reference line, the vehicles’ manoeuvre is based on the direction and status of signal (red or amber or green). If the signal is amber, then those vehicles which have already entered the intersection accelerate and clear the intersection. The vehicles which are before the stop line will start to decelerate based on their deceleration rates.

When the status of the signal is red, the vehicle will decelerate and come to stop. All the vehicles form a queue behind the stop line based on their direction of movement. Thus, all the vehicles accumulate on the intersection approach till the signal is red. Since mixed traffic has no lane discipline, left turning, straight through and right turning vehicles accumulate on the approach haphazardly ignoring lanes.

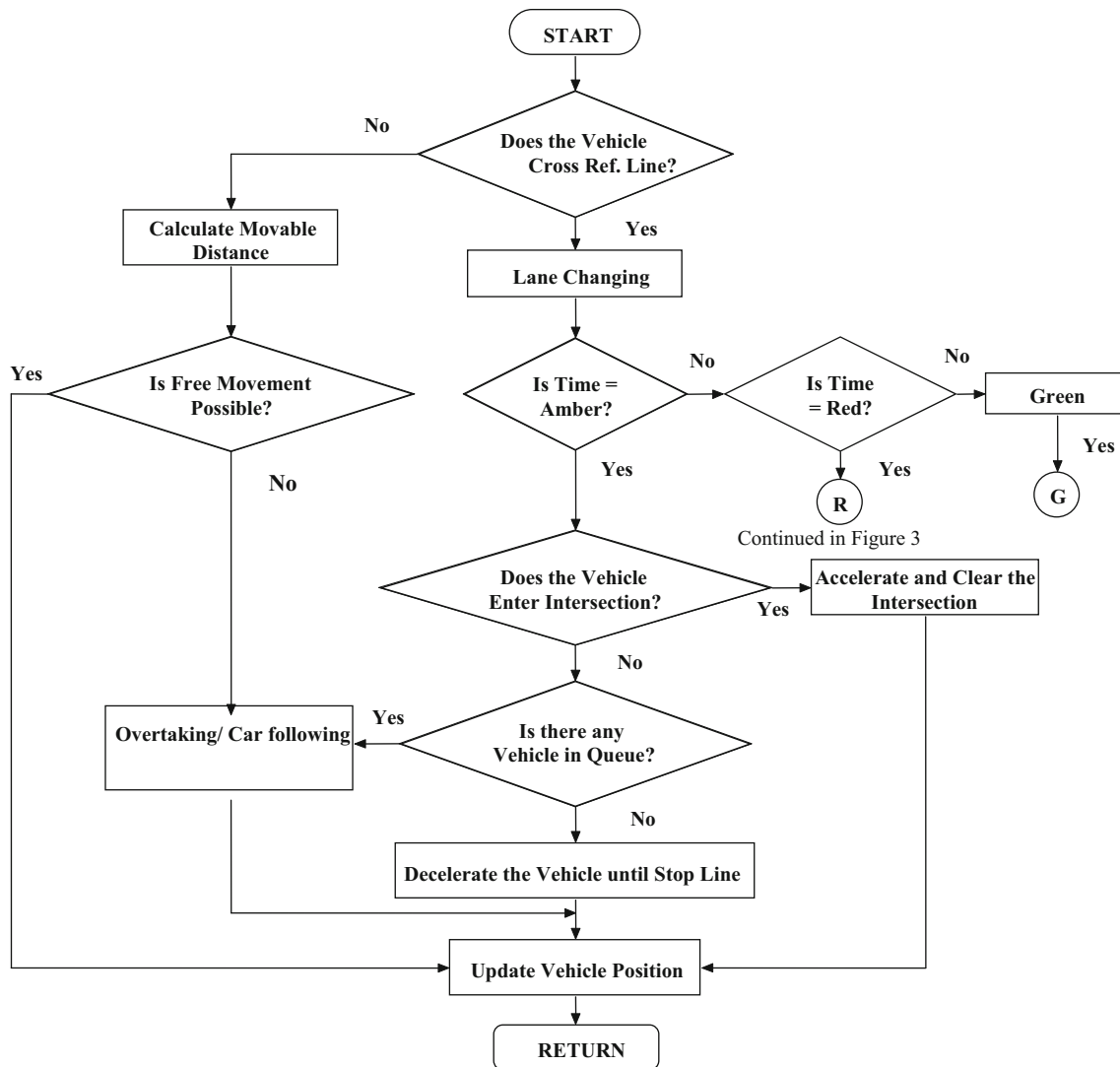


Fig. 2 Methodology for vehicle movement

Vehicle Dissipation

If the signal turns to green, vehicles waiting at the intersection approach start dissipating. Initially, the current speed of all the accumulated vehicles is zero. The position of all the vehicles is updated using equations of motion. Three manoeuvres are possible for individual vehicles when the vehicles clear the intersection area: free movers, overtakers and follower.

Vehicle Movement on Turn Lanes

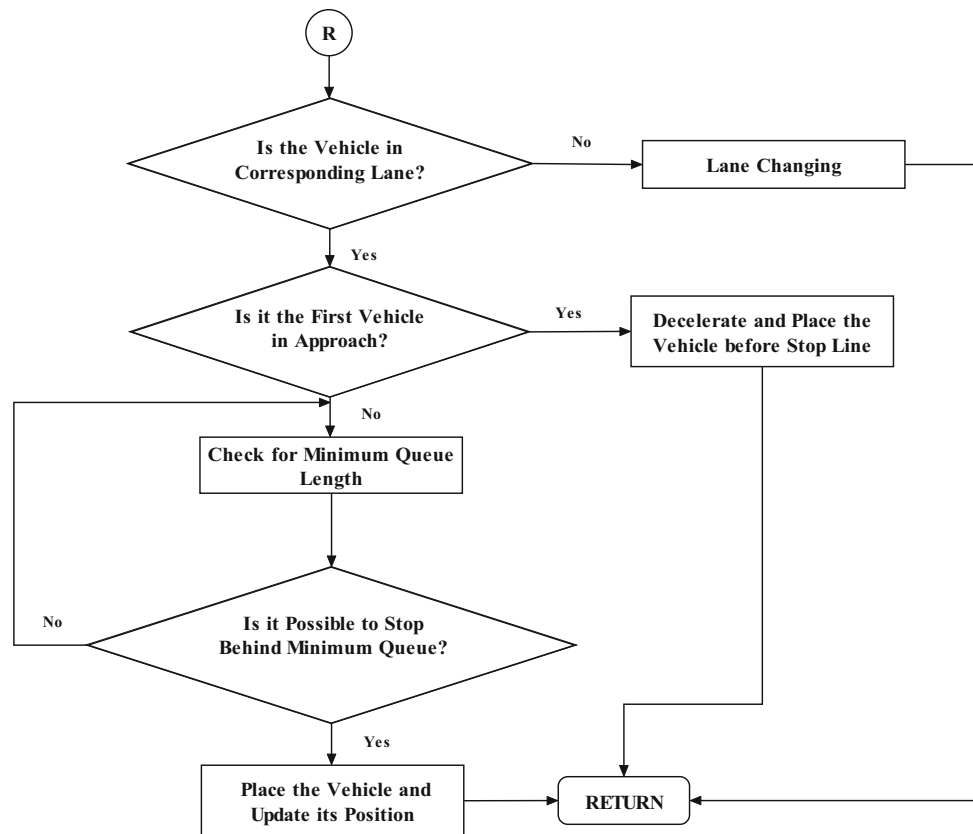
The model is also capable of simulating vehicular interactions on turn lanes. This logic forms part of the movement logic (Fig. 4). Movement of vehicles on turn lanes involves the following:

- Deceleration of vehicles approaching turn lanes, and
- Lateral movement of vehicles to reach turn lanes

The information required for building a simulation model of the turn lanes includes percentage of turning vehicles, total volume and turn lane length. In the simulation model, all the turning vehicles are assumed to be occupying the appropriate turn lanes. Right turn vehicles check for possibility of occupying the right turn lanes. Similarly, left turn vehicles attempt to occupy left turn lanes. This logic ensures that other movements (left and straight) are not allowed on right turn lanes; similarly, right and straight movements are not allowed on left turn lanes.

The methodologies for vehicle generation, placement, movement, accumulation and dissipation, and movement on turn lanes are integrated into one unit to simulate the movement of traffic on a road stretch. These are

Fig. 3 Methodology for vehicle accumulation



programmed coherently in OOP to develop the simulation model.

Implementation of Intersection Simulation Using Computer Program

The simulation model developed for this study was written in C++ programming language using OOP concepts. The OOP technique offers a highly sophisticated versatile programming environment for the development of large scale and/or complex software system. The benefits of OOP are easy maintenance, enhanced modification and reusability of the program.

Inputs to the Model

The user input variables for the simulation program are:

- Number of links
- Lengths and widths of the links
- Link traffic volumes in vehicles per hour
- Traffic composition (percentage of each type of vehicle)
- Type of movement by composition (percentage)
- Type of headway distribution

- Green time
- Yellow time
- Red time
- Total cycle time
- Total simulation time

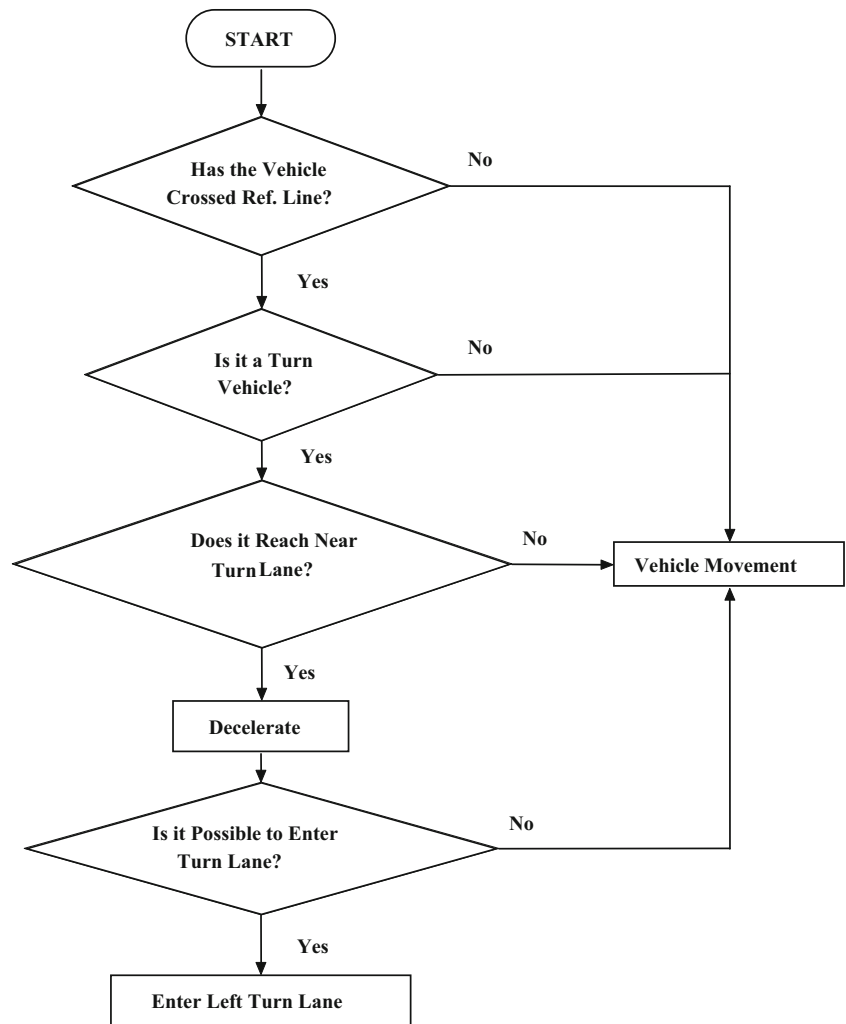
The input file also contains the following model parameters which can be changed, if required:

- Free speed parameters for each category of vehicles
- Dimensions of each type of vehicle
- Longitudinal clearance of vehicle at stopped condition
- Lateral clearances of vehicles
- Acceleration rate for each category of vehicles at different speed ranges
- Deceleration rate for each type of vehicle
- Reaction time of drivers
- Reference line
- Stop line
- Location of reference points for speed data

Outputs of the Model

Numerical results and animation of traffic flow are the outputs of the simulation model. During each simulation run, the following numerical results are obtained:

Fig. 4 Methodology for vehicle movement at turn lanes



- Number of vehicles accumulated at the intersection approach (queue density) during each signal cycle in PCU/sq m
- Number of vehicles crossing the stop line at each green phase (dissipation of vehicles) in PCU/cycle
- Average delay of all vehicles during each red phase
- Control delay of all vehicles
- Average delay of straight-through, right and left turning vehicles during each red phase
- Average speed of all the vehicles and average speed of category-wise vehicles

The model is also capable of displaying the animation of simulated traffic movements through the intersection. The animation module of the simulation model displays the model's operational behavior graphically during the simulation runs. It is a useful tool for validation of the model, and also, helpful in studying the changes in the behavior of the system when various input parameters are changed.

Model Calibration and Validation

The traffic data collected at an approach of a signalised intersection in Ashok Nagar, Chennai city was used to calibrate and validate the simulation model. This is an intersection of a four-lane divided major road crossing a two-lane undivided minor road. The approach carriageway width of the major road is 8.2 m and that of the minor road is 3.15 m. Traffic movements were captured using

Table 1 Comparison of field observed and simulated control delays

Vehicle type	Control delay (s/veh)		% Difference
	Observed	Simulated	
Two-wheeler	46	52	11.5
Car	44	50	12
Auto-rickshaw	44	50	12
Heavy vehicles	45	52	13.5

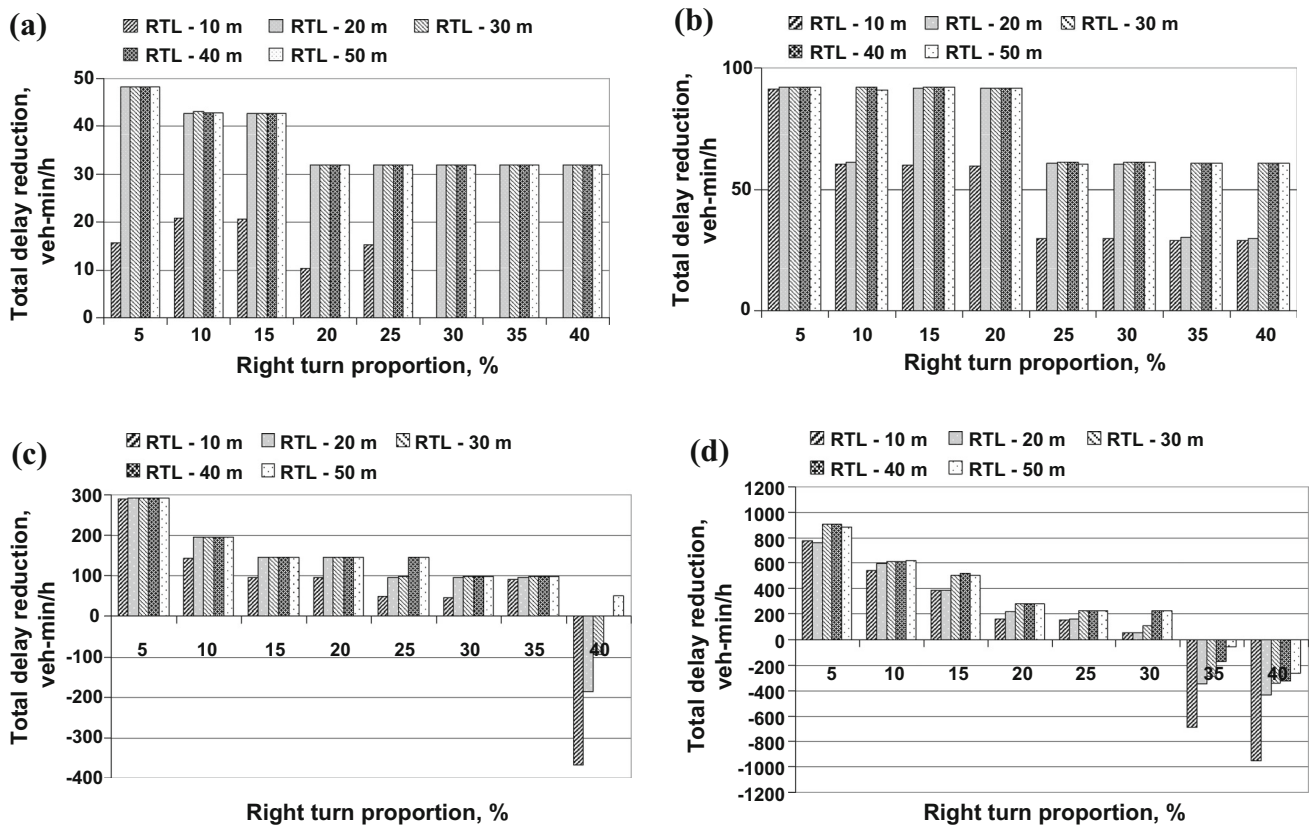


Fig. 5 Total delay reduction due to provision of RTL. a 1000 veh/h, b 2000 veh/h, c 3000 veh/h, d 4000 veh/h

videography during peak hours of traffic (8.30–10.30 a.m.) on three consecutive week days. The input data for simulation model were extracted from the video recording. Total traffic volume at the intersection approach during 1 h peak period was 4000 veh/h. Two wheelers (70 %) and cars (17 %) constituted major proportion of the traffic volume. Since pedestrian movements were minimal at this intersection, they have not been considered in this study. Straight-through, right turning and left turning vehicles comprised 75, 18 and 7 % of total vehicles, respectively. Cycle time of the signal is 134 s, out of which 75 s is the red phase for the major approaches. The parameters such as classified vehicle counts, headways, acceleration/deceleration/dissipation rates of vehicles, longitudinal spacing between successive vehicles, free speeds and signal timings were extracted from video data, were the inputs to the simulation model.

Control delay is taken as the validation parameter for the developed simulation model. Control delay is the portion of the total delay attributed to traffic signal operation for signalised intersections. Since locating cameras at vantage points had some limitations and restrictions in this study due to site conditions, the following methodology was adopted to estimate the control delay (different from

conventional control delay). A trap length of 100 m was selected before the stop line on an approach. The entry and exit times of each vehicle on this trap length during green phase were noted down. The difference between these two timings was taken as the free flow travel time. The congested travel time was calculated if the vehicle enters the starting point of trap length during green or red phase and exits the trap length after experiencing delay at the intersection approach. The difference between the above congested travel time and free flow travel time was taken as the control delay.

Control delay was observed in the field for each vehicle type during peak period of traffic flow. Control delay values were also obtained from the simulation model, through runs with three different random seeds. The observed and simulated values of control delay are shown in Table 1. Based on the hypothesis test, it is seen that simulated and observed values of control delays of each vehicle type are not statistically different at 0.01 level of significance.

Model Application

The above developed simulation model was employed to test the efficacy of CLTL and RTL for the case study

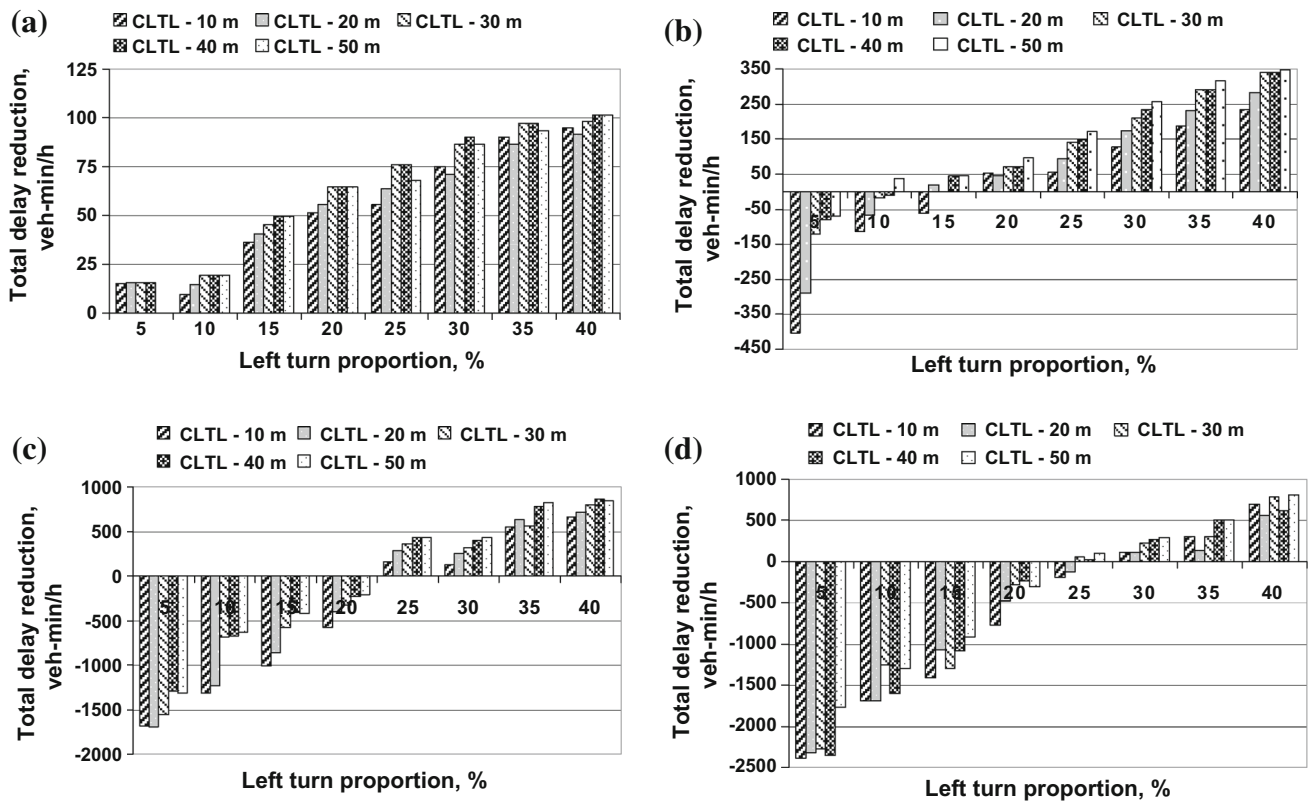


Fig. 6 Total delay reduction due to provision of CLTL. **a** 1000 veh/h, **b** 2000 veh/h, **c** 3000 veh/h, **d** 4000 veh/h

intersection. For this purpose, sensitivity analysis was carried out by varying the approach volumes, turn volume proportions and turn lane lengths to study the impacts of turn lanes on control delays of vehicles. For this purpose, control delays for the two major approaches without and with turn lanes were determined from simulation model. Each scenario was examined in two sets of simulation modeling runs: one with and one without a turn lane. Simulation runs were performed for 640 scenarios with a turn lane and 128 scenarios without it (total of 768 runs). Each simulation run represented 1 h of traffic flow during peak period.

Figure 5 shows the total delay reduction to vehicles due to provision of RTL. Total delay reduction of up to 166 veh-min/h is achieved for total volume levels of 500–2500 veh/h for right turn proportions of 5–40%. For total volume levels of 3000–4000 veh/h, total delay reduction is achieved in the range of 47–1226 veh-min/h for 5–30% right turn proportions. For 35–40% right turn proportions, total delay reduction is negative (disadvantageous) (increase in delay in the range of 46–1189 veh-min/h). Under these situations, the shortage of RTL space compels the turning vehicles to occupy the straight through lanes, which results in delay to vehicles. In the case of RTL, highest total delay reduction of 1226 veh-min/h (5%

right turn proportion and 50 m RTL) is achieved for total volume of 4000 veh/h.

Figure 6 shows the total delay reduction to vehicles due to provision of CLTL. For total volume levels of 500–1500 veh/h, total delay reduction is up to 269 veh-min/h. For 2000–2500 veh/h and 30–40% turn proportions, total delay savings is up to 559 veh-min/h. For 3000–4000 veh/h and 35–40% left turn proportions, total delay reduction is up to 955 veh-min/h. When the approach volume levels are in the range of 2000–4000 veh/h, for lower turn proportions, CLTL is disadvantageous (counter-productive!); here, the CLTL is under-utilized, thereby leading to non-left turning vehicles incurring higher delays. Highest total delay reduction of 955 veh-min/h is achieved for 40% left turn proportion and 50 m CLTL for 3000 veh/h.

Conclusion

A microscopic traffic simulation model was developed using OOP methodology for simulating heterogeneous traffic flow on turn lanes at signalized intersections. The validation of signalized intersection model, based on control delay, indicates that the model is satisfactorily

replicating the field conditions. The model specifically developed for RTL and CLTL can be effectively used for studies under various roadway and traffic conditions as prevailing in developing countries like India. RTL is found to be advantageous only up to certain approach volumes and right-turn proportions, beyond which it is counter-productive. As the approach volumes and turn proportions increase, RTL is found to increase the overall delays of vehicles. CLTL is found to be advantageous for lower approach volumes for all turn proportions, signifying the benefits of CLTL. It is counter-productive for higher approach volume and lower turn proportions.

This model can also be employed for scenario analysis and can be valuable to field traffic engineers in implementing traffic control/management measures for better utilization of intersection space, smoother flow of traffic and for effective regulation and control of traffic. It is proposed to develop the model further to incorporate the effects of network, different geometries, traffic, and traffic control conditions to build a comprehensive software package for heterogeneous traffic.

References

1. D.L. Gerlough, Simulation of freeway traffic by an electronic computer, in *Proceedings of the 35th Annual Meeting of Highway Research Board* (Washington DC, USA, 1956)
2. K.S. Pillai, Simulation techniques to study road traffic behaviour. *Indian Highways* **2**, 6 (1974)
3. M.F. Aycin, R.F. Benekohal, Stability and performance of car-following models in congested traffic. *J. Transp. Eng. (ASCE)* **127**, 2 (2000)
4. P. Chandrasekar, R.L. Cheu, H.C. Chin, Simulation evaluation of route based control of bus operations. *J. Transp. Eng. (ASCE)* **128**, 519 (2002)
5. C.F. Fang, L. Elefteriadou, Some guidelines for selecting micro simulation models for interchange traffic operational analysis. *J. Transp. Eng. (ASCE)* **31**, 535 (2005)
6. T.L. Popat, A.K. Gupta, S.K. Khanna, A simulation study of delays and queue lengths for uncontrolled T-intersections. *Highway Res. Bull. (IRC)* **39**, 71 (1989)
7. S. Raghavachari, K.M. Badrinath, P.R. Bhanu Murthy, Simulation of an urban uncontrolled urban intersection with pedestrian crossings. *Highway Res. Bull. (IRC)* **48**(1993), 29 (1993)
8. R.K. Agarwal, A.K. Gupta, S.S. Jain, Simulation of intersection flows for mixed traffic. *Highway Res. Bull. (IRC)* **51**, 85 (1994)
9. V.T. Rao, V.R. Rengaraju, Modeling conflicts of heterogeneous traffic at urban uncontrolled intersection. *J. Transp. Eng. (ASCE)* **124**, 23 (1998)
10. V.T. Arasan, K. Jagadeesh, Effect of heterogeneity of traffic on delay at signalized intersections. *J. Transp. Eng. (ASCE)* **121**, 397 (1995)
11. P. Maini, S. Khan, Discharge characteristics of heterogeneous traffic at signalised Intersections, in *Transportation Research Circular E-C018: 4th International Symposium on Highway Capacity* (Maui, Hawaii, 2000)
12. V.T. Arasan, S.H. Kashani, Modeling platoon dispersal pattern of heterogeneous road traffic, in *Transportation Research Board 82nd Annual Meeting* (Washington DC, USA, 2003)
13. B.R. Marwah, R. Parti, P.K.C. Dev Reddy, Modeling for simulation of heterogeneous traffic at a signalised intersection. *Highway Res. Bull. (IRC)* **74**(2006), 81 (2006)
14. A.G. Venkatesan, R. Sivanandan, Development of microscopic simulation model for heterogeneous traffic using object oriented approach. *Transportmetrica* **4**(3), 227 (2008)
15. A. Gowri, Evaluation of turn lanes at signalized intersection in heterogeneous traffic using microscopic simulation model. Ph.D. thesis (Indian Institute of Technology, Madras, Chennai, India, 2011)