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Development of Simulation Model for Heterogeneous Traffic with No Lane Discipline

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Abstract

Indian traffic can be considered as chaotic, with various types of vehicles present with no lane discipline. In order to model Indian traffic condition, it is necessary to incorporate both the vehicular heterogeneity and the 'no lane discipline' conditions in a meaningful way. Research has been made on weak lane discipline or vehicular heterogeneity as a single entity, but both these criteria are not present in a single model. In the present study, an attempt is made to quantify the unaccounted parameters of heterogeneity for Indian traffic into the existing car-following models to form a modified car-following model. A simulation model has been developed as a software program to study the performance of the modified car-following model in replicating Indian conditions. This model is used to simulate the traffic stream and some preliminary results are obtained. They are validated with field data collected from a major road in Delhi. The model is able to satisfactorily simulate the real-time traffic conditions. Analysis is carried out for roadway traffic characteristics, distribution of vehicles along roadway width and speed distribution of vehicles. The model, after extensive validation at a later stage, can be useful for future traffic experts for application.

Keywords: Heterogeneous traffic, traffic simulation model, no lane discipline, car following.

1. Introduction

Indian traffic generally consists of two salient features which distinguish it from the traffic pattern of developed countries: (i) weak or no lane discipline and (ii) heterogeneous traffic. In such traffic streams, vehicle not only interacts to vehicle present in front of it but also interact laterally with the vehicles present in its neighbourhood.

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Lateral interaction is necessary to be inculcated since vehicles also interact laterally due to absence of lane-discipline. This is also observed from the field data. Therefore, any study on Indian traffic scenario will be meaningful only if it can incorporate both the vehicular heterogeneity and the ‘no lane-discipline’ conditions. Gunay (2008) had made an attempt to developed a model for weak lane discipline traffic but that did not take into account the. Later, a modified Gipps’ model incorporating the vehicular heterogeneity is proposed by Ravishankar and Mathews (2011), however, this did not take into account the lateral interaction. This complexity and clubbing can be represented as a full-fledged traffic model as attempted in this paper.

The objective of this paper is to develop a traffic simulation model which can mimic the Indian traffic road conditions of heterogeneity and no-lane discipline. The scope of this paper is limited to unidirectional, mid-block traffic with ideal conditions on straight level road.

2. Literature Review

Literature review of simulation models is divided in two categories – (i) car-following models based on primarily longitudinal interaction of vehicles, and (ii) car-following models based on longitudinal and lateral interaction of vehicles. Both categories of model are presented briefly in following two subsections.

2.1 Car-following models

Car-following models describe the processes by which drivers follow each other in the traffic stream. These models have been studied for more than half century (for e.g. Pipes, 1953). It is clear then that a detailed understanding of this key process is now becoming increasingly important as opportunities for using new techniques and technologies become available. Literature review yields a long list of car-following models developed over the years by different. The research team of the General Motors (GM) Company produced five generations of their car following models which were all based on the analogy that the response of the following driver (acceleration or deceleration) is a function of the sensitivity of this driver and the stimulus. The Gazis-Herman-Rothery model (GHR model) (1958), the safety distance or collision avoidance (CA) model (1959), Linear (Helly) model (1959) are some of the popular car-following models amongst the list. A detailed description of all such car-following model can be obtained in Brackstone’s (1999) review paper. Cellular automata (CA) based models in which the cell is the fundamental units were initially developed by Nagel K. et al. (1992) for freeway traffic.

Gipps (1981) proposed a car-following model for the response of the following vehicle (FV) based on the assumption that each driver sets limits to his desired braking and acceleration rates. The model consists of a set of two equations that the driver of FV selects his speed to ensure that he can bring his vehicle to a safe stop if the leading vehicle (LV) suddenly stops. The speed of the vehicle is governed by two conditions that the vehicle (i) speed should not exceed its desired speed; and (2) accelerates to its desired speed with an acceleration initially increasing with speed and then decreasing to zero as the vehicle approaches its desired speed.

Later Gunay (2003) has modified the Gipps basic car following equation to incorporate the non-lane-based car following where due to off-centred positions of vehicles, the following driver does not assign leadership fully to the vehicle most in front. In the case of stopped LV, according to the basic car following case, FV will also stop, while in the non-lane-based (staggered) car following case, the following driver may have the opportunity to shift and pass the (stopped) LV. Allowed speed can be the most restrictive of two factors: (a) a speed at which the vehicle can decelerate (at time of passing) to the maximum speed allowed by the width of available space referred as escape corridor; and (b) a speed which should allow the following vehicle adequate time to veer laterally so as to safely avoid a rear-end collision (Gunay, 2007). The former is called maximum escape speed (MES) by the author. ‘t_{veer}’ (veering time) forms the latter factor and be used in the second part. However, this model was developed for only homogeneous traffic but included the weak lane discipline behaviour.

In 2011, Ravishankar and Mathews have developed a model that incorporates vehicle-type dependent behavior. The authors modified the widely used Gipp's model for different vehicle-type combinations. Three vehicle classes- namely, car, auto-rickshaw and bus were considered and the parameters b, $b*$ and T of Gipp's model were evaluated for each vehicle-type pair. These parameters are included in the current study. The equation of the model for the car-following case is as follows-

$$v^b_{t+T_j} = b_{ij}T_j + \sqrt{b^2_{ij}T^2_j - b_{ij}\left\{2\left[x^l_t - x^f_t - \alpha_{ij}S_i\right] - v^f_t T_j - \frac{(v^l_t)^2}{b^*_{ij}}\right\}} \quad (1)$$

Where, superscripts l and f stand for LV and FV respectively, and subscripts t and $t + T_j$ denote the quantity at end of time t (current time) and $t + T_j$, where T_j is the reaction time. b_{ij} and b^*_{ij} are the assumed deceleration of LV and FV respectively. α_{ij} is the sensitivity to the following distance. All the above mentioned parameters are for a lead-vehicle type i and following vehicle-type j. S_i is the effective-size of the LV. x stands for longitudinal position. Similar values of constants (provided in Ravishankar and Mathews, 2011) are also adopted in the proposed model.

2.2 Lateral and longitudinal control models

Several models have been proposed which have given the relationship between speed and lateral (or transverse) clearance required for a given vehicle. Arasan and Koshy (2005) developed a simulation model suitable for replicating heterogeneous traffic flow with weak lane discipline. In their analysis they found that transverse clearance between LV and FV depends upon their respective speeds and respective types. Transverse clearance for two different vehicle type pair can be expressed as a sum of each vehicle type. This inculcates the heterogeneity into practice. Maurya (2007) developed the CUTSiM model for heterogeneous traffic. Here, the author assumed that Safe Distance Headway (SDH- the headway at which driver feels safe) as well as Lateral Clearance (LC) linearly increasing with speed. Gupta et al. (1998) and Chakroborty et al. (2004) developed comprehensive models which describe both lateral and longitudinal control of vehicles based on a force field (potential field) analogy of the driving environment. But, the computational inefficiency of these models prevents their use in simulating large traffic streams.

3. Developed model

The section presents the proposed models of this study. The developed model of unidirectional traffic is motivated by two recent models- car-following model with lateral discomfort by Gunay (2007) and vehicle-type dependent model by Ravishankar and Mathew (2011). The former model doesn't address the heterogeneity parameters which are included in the latter model. However, Ravishankar and Mathew's model do not take into account the non-lane based car following, or lateral interaction between vehicles. The attempted study clubs these two models and develops a set of rules for various cases which govern vehicle speed during free flow (Case 0), basic car following (Case 1), MES-based car following (Case 2), and veer-induced car-following (Case 3), depending upon the case which would hit at the given time and condition. Following subsection presents a brief description of these governing rules of the proposed model.

3.1 Governing rules

Any vehicle in an Indian traffic condition is considered to undergo any one of following cases governing its speed-

- *Case 0:* v_0 $(= v^a_{t+T})$ It is based on the desired speed of the driver (which should not be exceeded). This is governing case when vehicle is in free-flow state. The movement is formulated as per conventional Gipp's model (1981).

- *Case 1:* v_1 (= $v^b_{t+T_j}$) corresponds to basic car-following if the leader and follower are in line (Eq. 2). Parameters of vehicle-type dependent model (Mathew, 2011) can be used in conventional car-following model (Gipps, 1981). All these cases are presented in Figure 1 for better description of different scenarios.

$$v^b_{t+T_j} = b_{ij}T_j + \sqrt{b^2_{ij}T^2_j - b_{ij}\left\{2\left[x^l_t - x^f_t - \alpha_{ij}S_i\right] - v^f_t T_j - \frac{(v^l_t)^2}{b^*_{ij}}\right\}} \quad (2)$$

- *Case 2:* v_2 (= $v^b_{t+T_j}$) that also corresponds to car-following condition in which the speed of the leading vehicle and the MES (maximum escape speed) value are the main constraints (refer Eq. 3). Here, Gunay's equations are used with modifying the deceleration and other parameters for different vehicle types as calculated by Ravishankar and Mathews. If FV has greater speed than LV, and if available lateral clearance is greater than 1.5 metres, vehicle can pass easily at its free-flow speed; or MES= v^a_{t+T}. If the gap available is zero, vehicle cannot pass, or in other words, MES=0.

$$v^b_{t+T_j} = b_{ij}T_j + \sqrt{b^2_{ij}T^2_j - b_{ij}\left\{2\left[x^l_t - x^f_t - \alpha_{ij}S_i\right] - v^f_t T_j - \frac{(v^l_t)^2}{2b^*_{ij}} - \frac{MES^2_{ij}}{b_{ij}}\right\}} \quad (3)$$

- *Case 3:* v_3 (= $v^b_{t+T_j}$) when the amount of lateral shift is significant, and speed of FV's are more than LV, the time needed to shift the vehicle laterally (t_{veer}) in order to avoid collision will be the governing factor, even if effective road width is high enough. That is, MES is treated as secondary in this scenario. To modify this equation to suit the requirements of Indian traffic, vehicle-type dependent parameters needs to be introduced. The position of the leading vehicle in stopped condition in the Gunay's model can be obtained by the equation,

$$x^l_{rest} = \left(x^l_t - \frac{(v^l_t)^2}{2b^*_{ij}}\right) \quad (4)$$

Since d_{body} is also another parameter which depends on the vehicle-pairs, a sensitivity factor α_{ij} (as per Ravishankar and Mathew, 2011) can be incorporated with this. Hence the modified equation will take the following form.

$$v^b_{t+T_j} \leq 2\left[\frac{\left(x^l_t - \frac{(v^l_t)^2}{2b^*_{ij}}\right) - x^f_t - v^f_t\frac{T}{2} - \frac{t_{veer}}{2}MES_{ij} - \alpha_{ij}d_{body}}{t_{veer} + T}\right] \quad (5)$$

The governing case in that instance would determine the vehicle velocity.

3.2 Simulation model:

A simulation model which can mimic the road conditions in actual Indian traffic scenario is developed for unidirectional traffic. The entire system is developed in C-language as an automation model. The system is updated after every time-steps (T_j) which is assumed to be the reaction time. The simulation process consists of (1) vehicle generation; (2) vehicle position updation and (3) analysis. The mechanisms involved in the vehicle generation and the analysis part are adopted from CUTSiM model developed by Maurya (2007). Initially, the road geometry (length and width) is decided. The vehicles are generated from one end of the road and leave from the other end similar to an open loop system. A parallel system of updating is adopted. Vehicles are generated according to defined vehicle types and their composition similar to filed condition. Generated vehicles are placed randomly within entire width of road with proper lateral and longitudinal gaps between generated vehicles. Then they are assigned various vehicle/driver related parameters like vehicle type (which governs length and width), current speed, v^f_t, risk-avoiding factor (which represents driver's characteristics and behavior), maximum desired speed for a particular vehicle type (values of 15, 20 and 30 m/s for auto-rickshaw, truck and car respectively are used in this model), interaction range (perceiving capacity of driver) and lateral clearance of vehicles. The lateral clearance values obtained from Nagaraj *et al.* (1990) are used and a linear trend is assumed for intermediate values.

Following assumptions are made while governing the vehicle movement-

- Movement will be governed with that case which gives maximum velocity v^f_{t+T} for FV at t+T interval.
- Velocity v^f_{t+T} should not exceed the desired speed of vehicle, V_j.
- Driver will maneuver his vehicle towards that gap which will give him minimum veering time t_{veer}.

Depending upon the governing situation described in Section 3.1, speed of FV at the end of the reaction time, v^a_{t+T} or v^b_{t+T} is calculated. The first case v_0 represent the free flowing behaviour while other three 3 speeds v_1, v_2, v_3 represent car-following cases. Vehicle lateral position (y^f_{t+T}) and longitudinal positions (x^f_{t+T}) are updated.

$$x^f_{t+T} = x^f_t + \left(\frac{V^f_t + V^f_{t+T}}{2}\right)T \quad \text{and} \quad y^f_{t+T} = y^f_t + (v_{veer} \times \mathrm{T}) \qquad (6)$$

Where y^f_{t+T} and y^f_t represent the lateral position of subject vehicle at times t+T and t. v_{veer} is the lateral manoeuvring speed of subject vehicle type. A static value of v_{veer} was used as 0.5 m/s for car, 0.75 m/s for auto and 0.25 m/sec for bus.

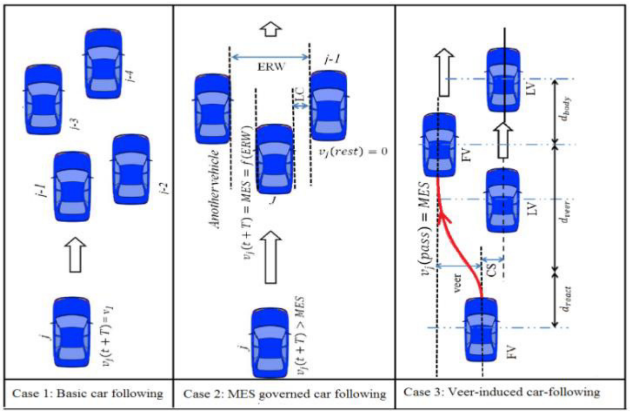

Fig. 1 Three governing cases of car-following used in the model. Note: ERW= effective roadway width

Physically, FV will search opportunities available within vehicle's interaction range and choose the best one that offers a higher speed at the next time-step. If there are no influencing vehicles within FV's interaction range, FV will move in a speedv^a_{t+T}. Else, car-following mode will be switched. All the feasible gaps through which vehicle can pass are calculated. If the leader and follower are in line, the amount of veer/shift required to overtake and time to veer is calculated for each possibility. In that case, v_3, calculated according to the veer value will be taken as v^b_{t+T}. However, if there are no feasible gaps, then the subject vehicle will continue following as per basic car-following case 1 with velocity v_1.

In case, there is no leading vehicle in line with following vehicle, available gap between two neighbouring leading vehicles is considered and maximum escape speed (MES) is calculated based upon the minimum lateral gap. Here, case 2 (MES-governed car following) will be dominating. If, at some other available gap, v_3 calculated is found dominating over v_2 (means vehicle will tend to veer for a better gap) then the case 3 will fire and value of v_3 is taken as v^b_{t+T}. The magnitude of v_2 and v_3 will depend on the clearance gap to be maintained which is a function of the escape corridor offered by the leading vehicles. Whenever v_3 is found dominating (lateral shift case), vehicle is shifted laterally according to the Eq. 9.

3.3 Algorithm

Algorithm of the model includes input conditions and initialization, various cases that can be followed and desired output. Variables such as driver, roadway, vehicle characteristics and traffic composition can be input by the user. Vehicles will be generated according to given flow and traffic composition. At each iteration upto total simulation defined by the user, position of each vehicle will be updated based on governing conditions. Updated vehicle lateral and longitudinal positions of the subject vehicle at the end of every time step is given as output. *Fig. 2* shows the flowchart of this simulation model. In the simulated model, total roadway length of 5 km is divided in 1 km of *generation zone,* 2 km of *warming-up zone* to allow vehicles to interact with each other and remaining stretch is used for *data collection* to avoid impact of vehicles' initial conditions.

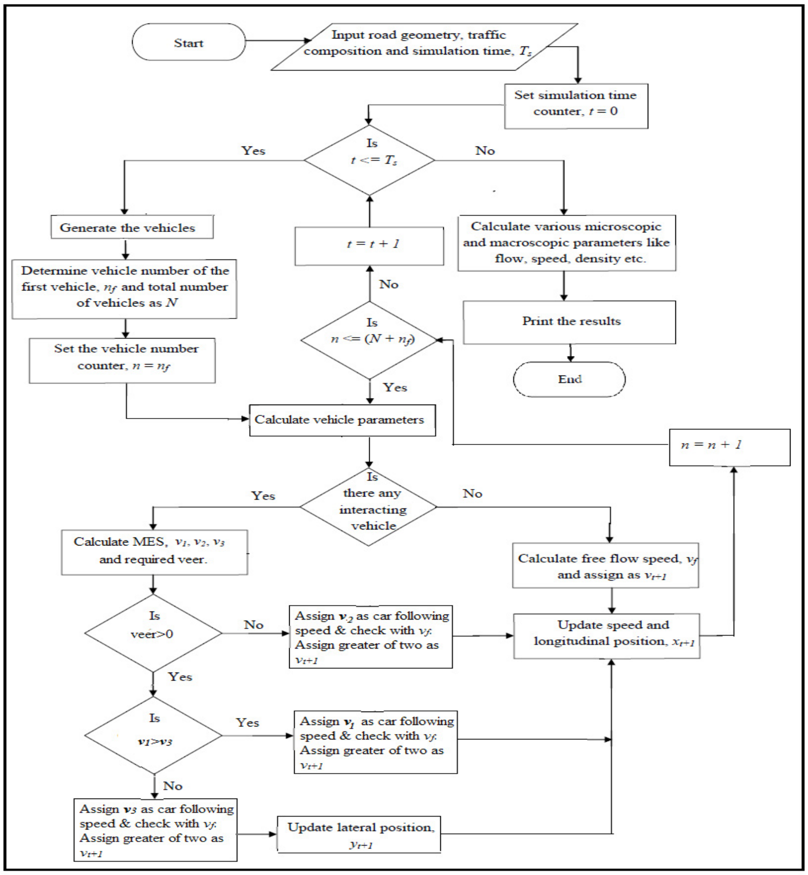

Fig. 2. Flow chart of the developed traffic simulation model.

3.4 Recording of field data

In order to validate the model, it is necessary to compare the simulation results with real world traffic data. For this purpose, the video recording of traffic stream on Outer Ring Road, Delhi at Pamposh Enclave (towards Hauz Khas) was carried out on 28th January 2012 during 9 am to 1 pm by Sreekumar (2012). This road was a six lane divided road with good road surface condition. Weather conditions were sunny. Top-frontal view of vehicles (recording from camera located on a Foot-Over bridge) was taken. For the field observations, flow and spot-speed of vehicles was calculated by noting the in-time and out-time of every vehicle within the section length (of 30 m). Similar scenario was simulated using developed model and speed-flow data points from simulated and observed traffic are compared. Further, simulated and observed speed distributions of different vehicle types are also compared. Results of this comparative study are presented in next section.

4. Analysis and results

For the validation and evaluation of the simulated model various analysis has been carried out and their results are presented in following subsections.

4.1 Analysis of lateral placement of vehicles

Field data collected is analysed manually to check the lateral placement of vehicles. This consists of creation of virtual grid on screen by using screen marker software. This analysis grid consists of lateral lines spaced at 0.2m gap as shown in *Fig. 3 (a)*. Similar scenario is simulated and lateral placement of vehicles are calculated from simulated stream. Observed a simulated results of vehicles lateral placement is plotted in *Fig. 3(b)*. It can be seen that, observed Indian traffic stream as well as simulated stream do not follow any lane discipline as centrelines of vehicles are placed all along the width of a roadway. It is observed that simulated results show little higher vehicle frequency than observed ones. In real traffic stream, driver does not prefer to drive in shoulder lanes due to frequent interruption by unauthorized parked vehicles, stopped auto or buses, etc. This biasness is not incorporated in the simulated model which resulted in higher number of vehicle playing shoulder lanes in simulated stream than the real traffic stream. Both results evaluated statistically for 5% significance level. The results are tabulated in *Table 1*.

Table 1: Statistical tests for lane distribution data and speed-flow relationship data from field and model.

Quantity	χ2 test at 5% significance level		Decision
	Calculated χ2	Critical χ2	
Lane distribution	4.9	16.919	Failed to reject Null hypothesis
Speed-flow relationship	22.97	44.97	Failed to reject Null hypothesis
Speed distribution of Cars	16.50	16.919	Failed to reject Null hypothesis
Speed distribution of Bikes	7.87	16.919	Failed to reject Null hypothesis
Speed distribution of Trucks	6.00	11.07	Failed to reject Null hypothesis
Speed distribution of Autos	10.04	14.067	Failed to reject Null hypothesis

Null Hypothesis: There is no significance difference between observed and simulation distribution

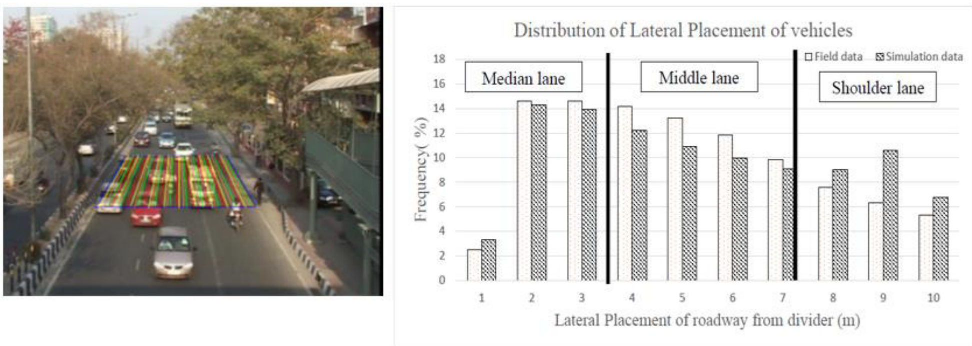

Fig. 3. (a) Analysis grid used for lateral placement data collection; (b) distribution of lateral placement of vehicles

4.2 Speed-flow and speed-density relationships

Speed- flow values obtained from simulated and observed traffic stream is presented in Fig. 4(a). It can be observed that nature of observed and simulated data are similar. Statistical evaluation results are presented in *Table 1*. The results are found to be satisfying at 5% significance levels. Derived speed-density plot is also presented in Fig. 4(b).

In order to obtain flow characterization result for homogeneous traffic (i.e. cars-only traffic) a traffic stream is simulated using developed simulation model. Simulation model is checked for basic traffic flow characteristics (speed-flow-density relationships) obtained from simulation mode. Model is simulated to obtain speed-flow-density relationship for varying road width conditions, that is, for 2-lane road and 3-lane road. Obtained speed-flow and speed-density relationships for two lane and three lane road are shown in *Fig. 5(a)* to *5(d)* respectively.

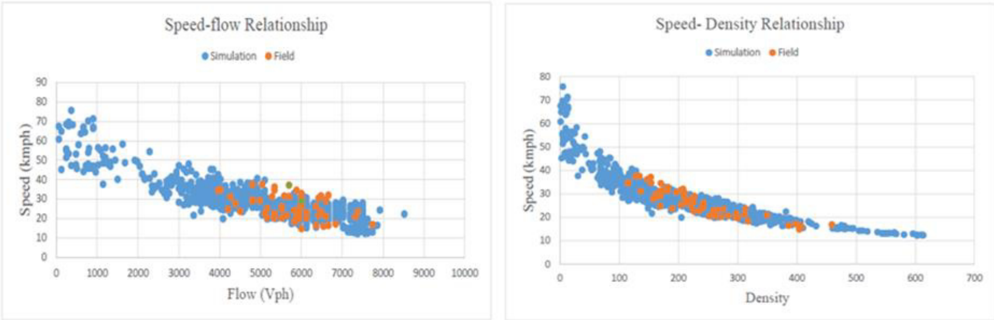

Fig. 4. (a). Speed-flow relationship; and (b) speed-density relationship for simulated and observed data

4.3 Speed distribution of different vehicle types

Speed distribution of different vehicle types (like car, bike, truck and auto) in observed and simulated streams are also plotted and compared in Fig. 5. Observed and simulated speeds of different vehicle types are also matches well. Comparison of speeds from observed and simulated also evaluated statistically at 5% significance level and found satisfactory.

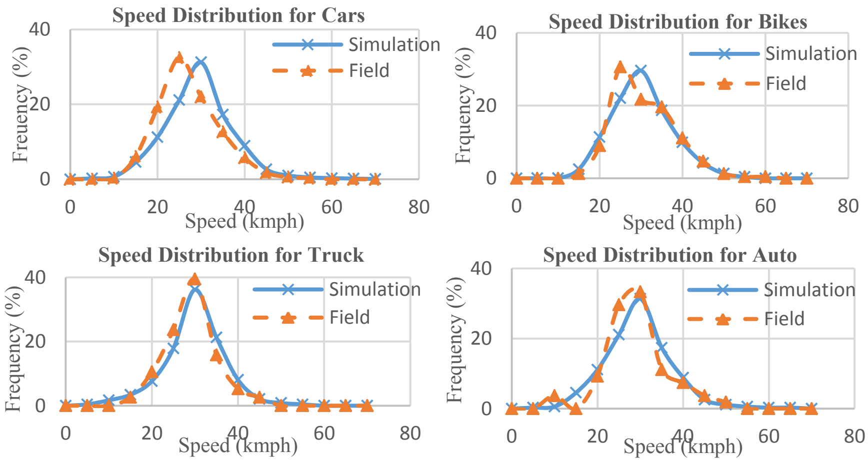

Fig. 5. Speed distribution of different vehicle types from simulated and observed traffic stream

4.4 Speed-flow and speed-density relationships of homogeneous traffic

In order to obtain flow characterization result for homogeneous traffic (i.e. cars-only traffic) a traffic stream is simulated using developed simulation model. Simulation model is checked for speed-flow-density relationships obtained from simulation model which are basic traffic flow characteristics defines characteristics of traffic stream. Model is simulated to obtain speed-flow-density relationship for varying road width conditions, that is, for 2-lane road and 3-lane road. Obtained speed-flow, speed-density and flow-density relationships for two lane and three lane road are shown in *Fig. 6(a)* to *6(d)* respectively. All of these plots show the expected nature of relationship between basic traffic parameters.

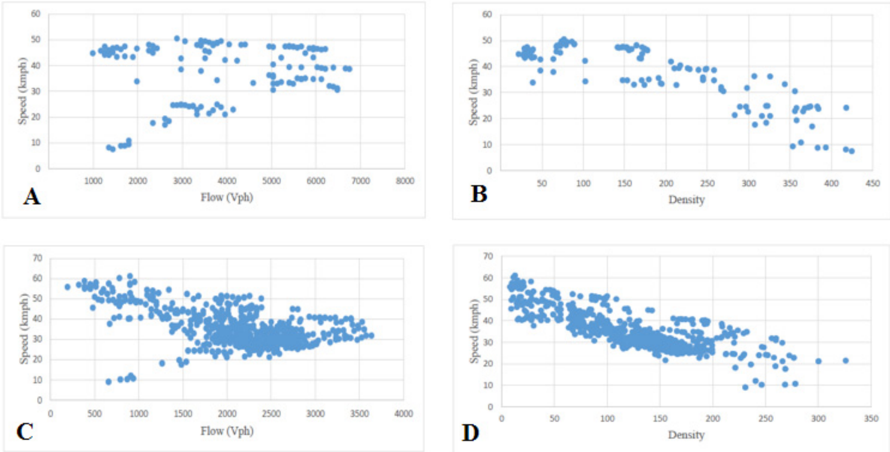

Fig. 6: For two lane roads, (a) speed-flow relationship; (b) speed-density relationship; For three-lane roads, (c) speed-flow relationship and (d) speed-density relationship.

4.5 Other simulation experiments

In order to analyse the simulation model microscopically, special runs of simulation model are performed under controlled traffic condition. In the experiment, behaviour of every leading and following vehicle pair for varying effective road widths and varying relative speed between each pair is recorded. Three different cases are considered in the experiment (a) Effective road width (ERW) < width of vehicle and relative speed is zero (Case 1a) and 10 kmph (case 1c), (b) ERW is just sufficient to pass (Case 2), and (c) ERW > minimum required road width to pass (Case3). From all the results, it is observed that the subject/following vehicle makes lateral shift to look for a better opportunity and after completing sufficient veer, it either follow or pass the leading vehicles according to the ERW, available. It every case, every case following vehicle behaviour was similar to what is expected in real world traffic. Due to space limitation, results for all experiment can't be presented here.

Results of Case 1a are presented in *Fig. 7*. In this case, ERW is not sufficient for FV to overtake the LV. Initially FV searches for better opportunity to overtake LV and if there are no interacting vehicles then FV tries to achieve its desired speed and then continues with its desired speed. However, if there is a LV present in the interaction zone and FV realises the presence of vehicle and will slow down. As there is no sufficient space for a FV to pass, it will continue to follow LV with speed equals to speed of LV. This situation where FV follows LV is termed as car-following phase. At car-following phase, follower will follow the leader by maintain safe distance headway and is dependent on FV type. *Fig. 7* explains behaviour of various leader-follower pairs. It can be seen from speed-time plot that whenever FV realises that LV is present within the zone of interaction, it slows down and FV starts following by attaining its speed equal to speed of leading vehicle. From distance headway-time plot, it can be observed that in car-following phase, FV starts following leader by maintaining sufficient time headway in order to avoid collision. This minimum distance headway is different for each vehicle type (although it is not visible in figure due high scale on Y axis).

Although the developed model is calibrated and validated with limited field data set, validation with bigger field database is recommended. Further, this model can be extended for inclusion of various roadway geometric conditions such as effect of curves, effect of gradients, etc. Thus, it is hoped that further exploration into this would open up opportunities to better utilize these modified car-following models in an Indian perspective.

5. Concluding Remark

In the present study, an attempt is made to develop a traffic simulation model accounting heterogeneity and 'no lane discipline' conditions together. Two different models (developed from Gipps model) which deals the weak lane discipline or heterogeneity issues individually are clubbed with necessary modifications. Scope for simulation model is limited to uninterrupted unidirectional traffic on straight and level mid-block section.

Developed model is validated at macroscopic and microscopic levels with traffic data collected from Delhi. Speed-flow-density relationships and speed distribution of different vehicle types obtained from simulated and real world traffic stream are compared and match is found satisfactory. Certain control experiments are also carried out to evaluate the performance of different vehicle pairs at microscopic level. Behaviour of vehicle pairs in simulated stream was found as expected in real world.

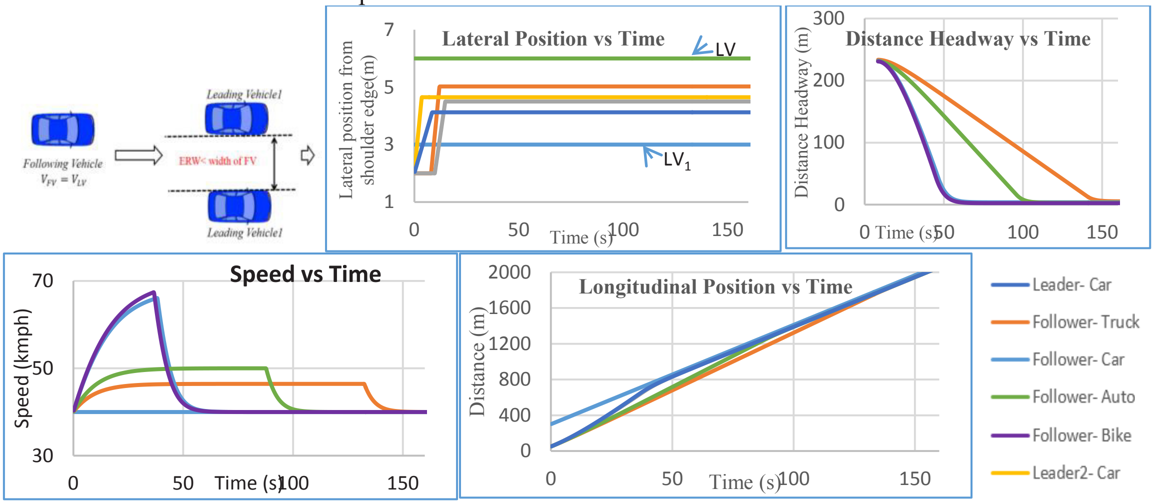

Figure 7 Simulated behaviour for various leader-follower pairs when ERW is lesser than width of follower and relative speed is 0 (Case 1a)

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