Need for a Comprehensive Traffic Simulation Model in Indian Context

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ABSTRACT
The large body of literature in the area of traffic flow theory and most of the existing traffic simulation models cannot be used as such in countries like India. Since the traffic condition in the Indian subcontinent are coarser- with innumerable ill-defined classes of vehicles interacting in an undisciplined manner, any study on this scenario will be meaningful only if it can incorporate both vehicular heterogeneity and no lane discipline conditions. This paper briefly discusses various past simulation simulation models and some recent models which are found more relevant to Indian context. Through the above discussions, the paper highlights the need of a comprehensive model which can simulate Indian traffic conditions in a realistic way. The description of CUTSiM model, which is found closer to the above mentioned approach is also presented. The results obtained, ensure the applicability of CUTSiM in Indian conditions in an appreciable way.

General Terms
Traffic simulation model, Driver behaviour, Heterogeneous traffic.

Keywords
Simulation model, Car-following, No-lane discipline, Heterogeneity, Microscopic models, CUTSiM

1. INTRODUCTION
In developing countries like India, the rapid growth of cities has resulted an extensive increase in the road network. The numbers of motorized vehicles have increased manifolds, especially during the peak hours. Congestion problems in cities simultaneously alarm both the users as well as the decision makers. Controlling, suggesting remedial measures, making changes to the existing traffic system in urban India is becoming more and more complex day after day. Traffic Engineering is hence coming to the limelight in India to understand and analyze the traffic stream behaviour for an efficient design of traffic facilities. Unfortunately, the large body of literature that exists in the area of traffic flow theory cannot be used as is in countries like India due to the following reasons. Firstly, traffic here includes innumerable classes of vehicles having different operating characteristics. Secondly, drivers in India do not follow lanes i.e., the traffic streams do not have lane discipline.

Therefore any study on Indian traffic scenario will be meaningful only if it can incorporate both vehicular heterogeneity and “no lane discipline” conditions. To analyze the traffic stream behaviour which is very complex and stochastic in nature, one need to understand how vehicles interact each other not only along the longitudinal but also along the lateral direction of the lane and also with the existing traffic facilities? So while modeling the heterogeneous traffic conditions prevailing in most of the developing countries, the system have to be viewed microscopically. The complexity of stream behaviour and the difficulty that exists with performing experiments make computer simulation an important analysis tool in traffic engineering. Secondly, through simulation, it is easier to model individual vehicle actions in different situations than to understand the system dynamics directly. By making use of different traffic simulation models, one can simulate large scale real-world situations in great detail.

This paper is being written, identifying the necessity of a comprehensive microscopic traffic simulation model which can simulate Indian traffic scenario in a realistic manner. A brief review of various categories of models consisting of longitudinal control models, Lateral control models and combined lateral and longitudinal control models is included in this paper. It is felt that the quality of any model lies in the level of realism present in the traffic stream simulated using that simulation model. A few recent models are concisely explained to address the fact that the assumptions made in them are far from Indian traffic conditions.

2. A PRECIS OF MICROSCOPIC TRAFFIC SIMULATION MODELS
A realistic model of driving or driver behaviour must be a comprehensive model which models both lateral control (steering control) and longitudinal control (speed control) under the impact of both roadway and traffic features [1]. According to this aspect of control, microscopic models can be categorized into (i) longitudinal control models, (ii) lateral control models, and (iii) comprehensive models and discussed in present section.

2.1 Longitudinal Control Models
Longitudinal control models assume that the driver behaviour is influenced only by leading vehicles traveling in the same path or lane. This assumption is largely true where the road characteristics are reasonably same for long distances, vehicles have well demarcated paths and vehicles do not generally cross these demarcations. The process of achieving the longitudinal control is referred to as car-following in transportation literature. The car-following behaviour is basically, a human perception-reaction process, where driver of the following vehicle (FV) attempts to reach a stable condition (by accelerating or decelerating) and then maintain it while following a leading vehicle (LV). In this process of reaching a stable situation and maintaining it, the driver of following vehicle continuously takes corrective actions by accelerating or decelerating [1].

Research on car-following theory started dates back to the mid 20th century. From then, a lot of studies have been done in order to develop ever more accurate models on car-following. In the early 1950's, car-following behaviour was modeled using a stimulus-response concept. The research team of General Motors (GM) Company produced five generations of 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. This stimulus is generally the relative speed between the two vehicles and the sensitivity term is affected by the distance headway between the two vehicles and the speed of the following vehicle. Some models suggested a linear increase of minimum safe distance headway with increasing speed. Subsequently safety distance models were formulated based on the driving tendency to keep a safe following-distance. The model proposed by Gipps relates the sped of FV to parameters like distance between LV and FV, desired speed of FV, current speeds of FV and LV, maximum acceleration of FV, maximum decelerations of LV and FV through a set of two equations [2].

Later psycho-physical or action point models were developed based on the idea that a driver can be in different driving modes like free driving, approaching, following and braking. The driver behaviour in car-following mode was also modeled using certain rule-based models by specifying some set of rules on what to do under different driving scenarios [3]. Although the cellular automata models which can be considered as the advanced series of rule-based models are computationally efficient and can simulate large traffic streams, the simulated streams often do not replicate many of the observed microscopic properties of real-world streams. There is many more car following models available in the literature, in addition to the above summary. Each model has certain advantages and disadvantages. A detailed review of these models can be found in [4]. A few traffic flow models which seem to be more relevant in Indian context are briefed in the next section of this paper.

2.2 Lateral Control Models

Most of the works on lateral control models relates to how different roadway objects and obstacles initiate a lateral shift in driver's path. These studies reinforce the fact that objects other than those on the travel path of a vehicle also have impact on the driver's actions. The steering control in lane maintenance was also studied under very restrictive conditions. The intent of this study was to see how precisely humans can steer the vehicles. None of these studies, however, actually try to model what path a driver would like to use in the presence of various static and dynamic obstacles [1].

2.3 Comprehensive Models

As discussed above, the final goal of microscopic modeling is to be able to devise a comprehensive model which models both lateral and longitudinal control of vehicles as a comprehensive whole. There are comprehensive models developed based on a force field (or potential field) analogy of the driving environment which consist of goals (where the driver wants to be) and obstacles (dynamic as well as static).The force field models perform well when a simulated driver's or a simulated platoon's behaviour is evaluated. But, the computational inefficiency of these models prevents their use in simulating large traffic streams [5].
The CARSIM simulation model, developed for the simulation of stop-and-go traffic had incorporated a collision a collision algorithm and a minimum separation constraint for car-following [6]. Another simulation model, INTELSIM was also developed in which the reaction times of drivers were not restricted by simulation-time steps [7]. Since all these studies have been conducted under relatively homogeneous traffic conditions, these models cannot find their application in heterogeneous traffic streams. Now a days, traffic simulation packages like CORSIM and VISSIM are frequently used as tools for analyzing traffic. VISSIM is a microscopic, time-step and behaviour based simulation model developed to analyze the full range of functionally classified roadways and public transportation operations. Since all these are commercial software packages, sufficient changes to the internal parameters satisfying customized user requirements cannot be made easily.

3. OTHER TRAFFIC FLOW MODELS RELEVANT TO INDIAN SCENARIO

Arasan and Koshy developed a simulation model suitable for replicating heterogeneous traffic flow, based on the interval scanning technique with fixed increment time advance [8]. It has been found that the method of treating the entire road space as a single unit, for the purpose of simulation, and representing the different types of vehicles as rectangular blocks on the surface, is appropriate for simulating highly heterogeneous traffic flow. This model adopted sequential system to update the positions of vehicles.

Dey et al. have developed simulation program for traffic flow modelling on a two-lane road. Random placement for vehicles is assigned within a lane [9]. Moreover, some clearance is also incorporated from edge and shoulder of a roadway. Logical overtaking is implemented using a set of well defined rules to imitate continuous decision making of drivers. This study is not limited only to speed-flow relationship, while model is applied to estimate the capacity of the road, to check the variation of PCU (passenger car unit) values for mix traffic, and effect of traffic mix on capacity.

A modified car-following model has been developed by Gunay, with particular reference to weak discipline of lane based driving [10]. The movement of the following vehicle was formulated as a function of the off-centre effects of the leader(s). This incorporation of lateral friction offers a potential breakthrough in the fields of car-following theory and microscopic simulation of traffic flow.

Using a stopping-distance car following approach, Gunay pointed out the effect of the travel path width on the following vehicle, and the reduced following distance with increased lateral separation between the leader and the follower. The model also incorporated the concept of Maximum Escape Speed (MES) to the conventional Gipp's model. But the model had no reference on vehicular heterogeneity to find their applications in Indian context.

Further attempts were also made to modify the widely used Gipp's car-following model to find its use in heterogeneous traffic conditions. The model stated in [11] had incorporated the vehicle-type dependent parameters to the conventional model. The choice of model and their parameters can be estimated only after elaborate field studies addressing driver and vehicle heterogeneity. Even though this approach attempted to model explicitly the vehicle-type dependent behaviour in traffic simulation, the effect of vehicle-type on lane changing and non-lane based movement of vehicles needs to be considered in order to replicate traffic flow in a greater detail.

CUTSiM which was developed as a comprehensive microscopic model, is found to be more relevant in Indian perspective since it can be used for simulating the traffic stream with and without lane discipline. A description about this model is also briefed in the next section of this paper. From the review of various microscopic simulation models presented in this paper, it is very clear that a full-fledged simulation model need to be developed which can simulate Indian traffic conditions in a realistic way.

4. CUTSiM – COMPREHENSIVE UNINTERRUPTED TRAFFIC SIMULATION MODEL

As discussed earlier, the ultimate goal of modeling traffic flow must be to evolve a comprehensive model of driver behaviour which can handle both longitudinal and lateral interactions and also simple enough to be used to simulate large traffic streams. CUTSiM (**C**omprehensive **U**nidirectional **T**raffic **Si**mulation **M**odel) developed by Maurya (2007), find its use as a suitable program package to simulate heterogeneous, uninterrupted traffic streams with or without lane discipline i.e. similar to Indian traffic streams. Like any microscopic models, the description of traffic stream behaviour presented in this model is also a discussion on drivers and their behaviour. The model concentrates on studying and modeling unidirectional and uninterrupted traffic streams and also, the program code was written in C language. It was developed as a discrete-event traffic simulation model, using interval scanning technique with fixed-increment time advance. The road space is discretized into cells with specific dimensions *l* and *w*. Time is discretized into small time-steps, Δt at which the system is updated. This model consists of two modules; one of the modules defines the actions of the vehicle aimed at controlling its lateral position on the road while the other module defines the actions of the vehicle aimed at controlling its speed. Both the modules are discussed in next two subsections.

4.1 Lateral Control Module

The lateral control module describes how a driver chooses a suitable steering angle to maintain his/her vehicle on the "best path." The best path is assumed to be the one which allows a driver to move safely and at satisfactory speeds given the driving environment at that time. It is hypothesized here that in order to choose the best path the driver evaluates the goodness of each available path within its vicinity based on (i) the maximum distance headway available on the path, (ii) the difficulty in maneuvering towards that path, (iii) the obstacles present in and around the path,(iv) whether the path ends up (within a short time) leading the vehicle to the edge of the road, and (v) whether the path crosses the expected path of faster moving vehicles coming from behind. Simple functions are defined to capture the impact of these factors on goodness of path. All these individual goodness values are multiplied to determine the overall goodness of a path. The path which has the maximum goodness among the available paths (within the vicinity) at any instant of time is assumed as the best path for the movement of that vehicle that point of time. Also, all the goodness values based on different criteria mentioned above have equal weight in deciding the best path based on the maximum goodness. So, all these five goodness values vary within the equal range (0 and 1).

4.2 Longitudinal Control Module

The longitudinal control module defines the actions of the driver (in terms of acceleration or deceleration) which he/she employs to control the speed or alternatively the longitudinal position of the vehicle. It is postulated that the driver's behaviour can be classified in two types: (i) when the driver behaviour is not impeded by the actions of other vehicles, and (ii) when the driver behaviour is impacted by the actions of the leading vehicle on the chosen path. The first type is referred to as "free-flow" behaviour while the other is referred to as "car-following" behaviour. In the free-flow mode, actions of the driver is assumed to depend on the difference between his/her desired speed (speed which one wants to maintain if not impeded by other vehicles for a given road condition) and the current speed. Actions of the driver in car-following mode is assumed to depend on the anticipated relative speed, relative acceleration and the deviation of available distance headway from stable distance headway (distance headway at which a driver feels safe while moving at a given speed). The distance headway at which a driver switches from one mode of behaviour to another is referred to as the threshold distance headway.

CUTSiM utilizes both modules at every instant of time for each vehicle to simulate large traffic streams. It employs a parallel update strategy and incorporates the driver reaction time explicitly. Vehicles are initially generated over the entire road space of vehicle generation stretch with desired lateral and longitudinal clearances between generated vehicles. CUTSiM can be used to simulate single lane traffic streams as well as traffic streams on wide roads with and without lane discipline. In fact, it has been shown that lane behaviour can be obtained as a special case of "no lane behaviour" traffic streams.

5. RESULTS

CUTSiM is used to simulate single lane traffic streams as well as traffic streams on wide roads with and without lane discipline. Further traffic streams on roads of varying widths and surface conditions with a variety of vehicle mix have been simulated. These simulated streams have been studied for their microscopic and macroscopic properties. Some of the study results are briefed in this paper. Results from these studies and their comparisons with appropriate observations from real-world traffic streams have been used to validate CUTSiM.

5.1 Microscopic Analysis

The various microscopic properties studied include (i) stability behaviour of CUTSiM in car-following situations, (ii) acceleration noise, and (iii) speed distribution. CUTSiM, when used to simulate single lane homogeneous traffic flow with cars, only the longitudinal control module is operational and this situation can be used to analyze car-following behaviour. It is observed that simulated stream shows local stability, closing-in and shying-away behaviour but detailed results are not provided due to space restriction. A five vehicles platoon is simulated to study asymptotic stability. All the vehicles are placed at 32.31 m (106 ft) initial distance headways and 18.29 m/s (60 ft/s) initial speed. leading vehicle (LV) moves at constant speed till 1 s then it accelerated its speed from 18.29 m/s to 24.38 m/s (80 ft/s) in 4 s then decelerate from 24.38 m/s to 12.19 m/s (40 ft/s) in 8 s and again accelerated to attain its initial speed in 4 s. Distance headway variation between other following vehicle due to this perturbation of LV is presented in Fig. 1. It can be seen from figure that perturbation gets damped as it propagated upstream side (i.e. *i* increases) which shows the simulated stream is the asymptotically stable. The above mentioned study establishes that CUTSiM behaves realistically from the perspective of car-following.

Although acceleration noise is an average quantity, it is still discussed here because it relates to driver actions in terms of acceleration at every time-step.

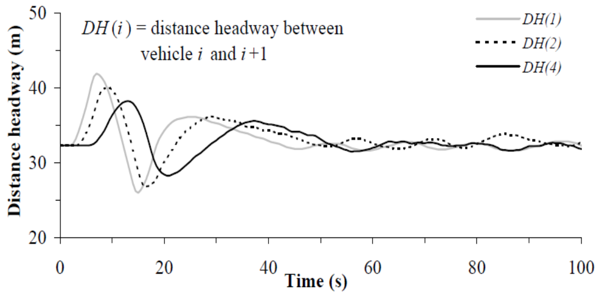

Fig 1: Study of asymptotic stability of single lane traffic simulated using CUTSiM

In a way, this value indicates the driving pattern of drivers. Fig. 2 shows the acceleration noise of different vehicle types at different density levels in simulated streams on two lane wide road without lane discipline. It is observed that acceleration noise initially increases with density and later it decreases with further increase in density. This is similar to as observed by other researchers [14].

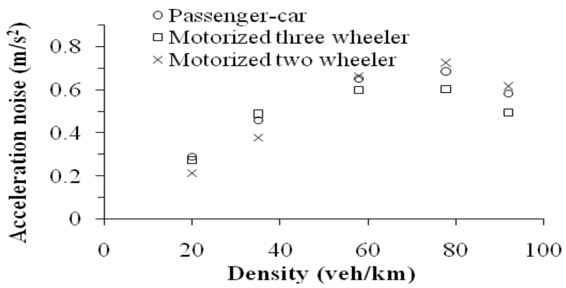

Fig 2: Acceleration noise obtained from CUTSiM simulated heterogeneous traffic stream on two lane wide roads without lane discipline.

The observed speed distributions from Delhi-Gurgaon highway (NH8) is compared with the simulated speed distributions in order to study how well CUTSiM replicates a real-world traffic stream on wide roads with no lane discipline. The comparison is shown in Fig. 3. The traffic on Delhi-Gurgaon highway is unidirectional, uninterrupted and mainly consists of passenger cars (≈70%) and motorized two wheelers (≈30%). The road is 14.6 m wide. The observed speed distribution is found to be reasonably symmetric around the mean speed of 64.16 km/hr. A similar traffic condition has been simulated using CUTSiM and the speed distribution of simulated traffic is also distributed symmetrically around a mean speed of 64.92 km/hr. The observed and simulated data shows a good match with an RMS error of 0.016 and also satisfies the KS-test at 5% significance level. Speed-flow comparison of observed and simulated stream is also compared and result is presented in macroscopic analysis subsection.

5.2 Macroscopic Analysis

The macroscopic features include pair wise relations between speed, flow and density. These macroscopic properties of single lane and two lane traffic flow are evaluated using the flow simulated using CUTSiM. The simulated stream is assumed to have 100% passenger-cars. Idealized speed-density and speed-flow plots presented in Fig. 4 and 5 respectively shows the behaviour as expected in real-world traffic streams. Table 1 shows the capacity values obtained and those suggested in Highway Capacity Manual for both the above cases. It can be observed from the table that unlike the multilane highway, doubling the road width does not result in doubling of capacity of road. This is due to increase lateral interaction between vehicles in case of no lane discipline traffic.

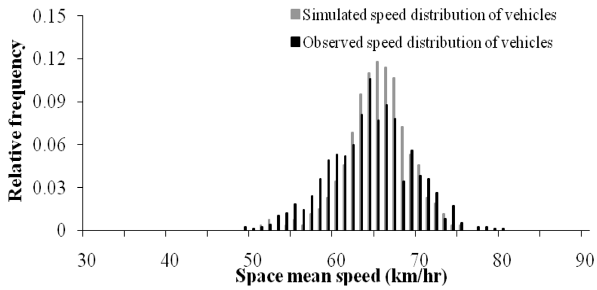

Fig 3: Speed distributions obtained from simulated and observed traffic at Delhi-Gurgaon highway

Table 1. Obtained and Suggested Capacity values

Road width (m)	Capacity obtained using CUTSiM in passenger-cars/hr/lane	Capacity suggested in Highway Capacity Manual in passenger-cars/hr/lane
3.6	2175	2200
7.3	3975	NA
11.0	5600	NA
14.6	7150	NA

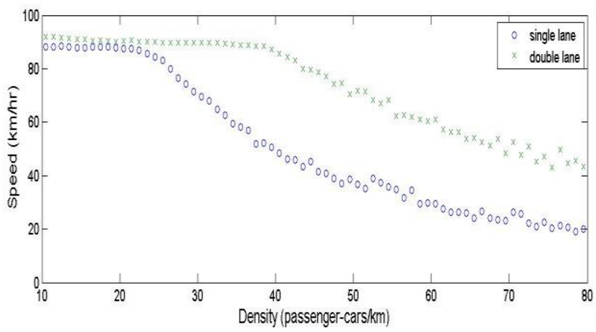

Fig 4: Speed-density relationship obtained from simulated single and two lane road traffic stream using CUTSiM

For validation purpose, a comparison of speed-flow relation observed at Delhi-Gurgaon highway and that obtained from a traffic stream simulated using CUTSiM (for similar road conditions and vehicle mix) is also made. Fig. 6 shows a good match in observed and simulated speed-flow relationship and the capacity values are also found to be a closer match with an RMS error value of 1.76 and it also satisfies the KS-test at 5% significance level.

CUTSiM can even model lane behaviour as a special case of the more generic "no lane discipline" behaviour which proves CUTSiM as truly comprehensive model to simulate all kinds of traffic streams. The way CUTSiM converted to behaviour with lane discipline is by simply suggesting that a driver shifts to a new path only if the new path is "substantially" better than the present otherwise continue in his/her current path even if its "goodness" value is not the best. Note that in the "no lane discipline" case the driver would have moved to the path with maximum goodness even if the gain in goodness over current path was marginal. CUTSiM is evaluated for various microscopic and macroscopic properties of lane disciplined traffic streams like speed-flow relationship, speed distribution, acceleration noise, time headway distribution, lane change frequency, etc. However these results are not presented here due to space restrictions.

CUTSiM can simulate large traffic streams in reasonable time (i.e. it can simulate 4000 vehicles in less than half of the real time) on desktop computers (with dual core 2.2 GHz processor and 32 GB RAM).

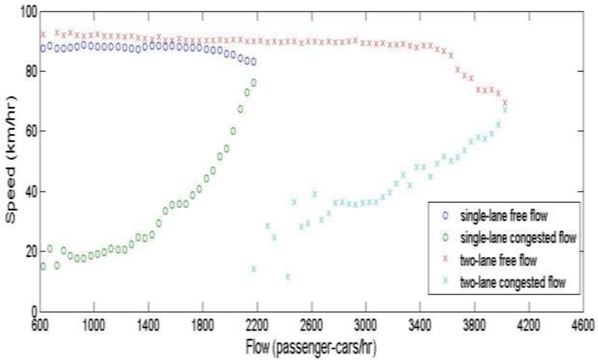

Fig 5: Speed-flow relationships obtained from simulated single and two lane road traffic stream using CUTSiM

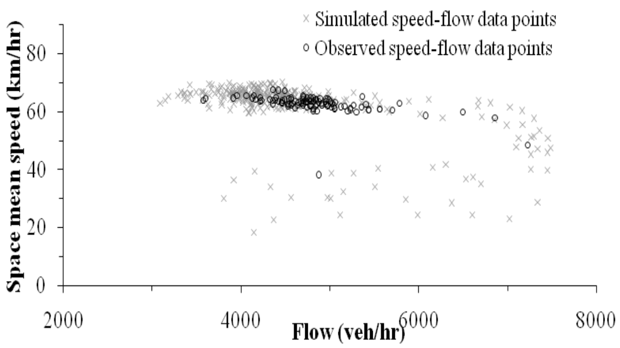

Fig 6: Speed-flow relationships obtained from simulated and observed traffic at Delhi-Gurgaon highway

6. CONCLUSIONS

As explained before, this study is primarily motivated by the necessity of a comprehensive simulation model which can simulate Indian traffic conditions in a realistic way. Keeping in view of this, various models relevant to Indian context have been discussed in the previous sections. It can very well observed from the discussion on these models that even though there are models which can incorporate vehicular heterogeneity, they cannot be applied directly to simulate Indian traffic scenario. This is due to the fact that the drivers here do not follow any lane discipline. Therefore in the present study, the methodology of a comprehensive model which is found closer to replicate Indian traffic conditions was briefly explained and the results were analyzed both microscopically and macroscopically. The results of above studies show that CUTSiM is able to simulate Indian traffic streams with and without lane discipline on various kinds of roads with different vehicle mixes reasonably realistically. It has been seen that CUTSiM can simulate large streams very realistically with limited computation power. Further, a large scale validation with field data is required for its wider acceptability. However, a full-fledged comprehensive simulation model needs to be developed considering the complex behaviours such as vehicular interactions in bidirectional streams and their non-lane based movement. With such step by step improvements, simulation models can be expected to get refined, that in future, there will be models that can study Indian traffic conditions in an appreciable way.

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