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Need for an Integrated Modelling Approach for Mixed Traffic Flow Phenomena

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Abstract
Traffic flow modelling can be in general categorised into three broad categories. Macroscopic models are generally based on aggregate level of traffic flow; whereas microscopic tools are more disaggregated and dynamic in nature. Benefiting from the steadily increasing availability of affordable computing power, these more detailed models have become the tool of choice for operational studies, commonly in the form of microscopic simulators. Among other dynamic models, mesoscopic ones are a compromise between the macro and micro levels. With the introduction of new technologies, data of unprecedented quantity and ultimately quality, development of next generation simulation models becomes an interesting research direction.This paper proposes the need for next generation simulation models and presents a lead to development of integrated models. The driver behaviour is a cause-reaction approach involving several tasks within a short time interval. Hence an integrated system comprising of driver decision making and the inter-dependence among the decisions and anticipation capabilities better replicates the realistic diving behaviour. These integrated models are driven by the distinct difference in driving behaviour, vehicle-type characteristics, level of traffic etc. These kind of models are more apt particularly for Indian mixed traffic conditions where the static and dynamic characteristics of the vehicle vary widely.

Keywords*: Mixed traffic, integrated models, reaction time, vehicle-type, lateral behaviour*

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INTRODUCTION

Traffic flow modelling has been one of the widely used modelling phenomena in transportation engineering. A number of models were developed over the past years leading to several class of models. These models have been widely used in several of the traffic simulation tools at microscopic and macroscopic level. In many of these models, an attempt was made to predict the driving task in following, closing behaviour etc. However the real driving task is difficult to predict and model. Some underlying assumptions are made in the car-following models such as safe following distance, optimal speed etc. In real situation, the driver behaviour or the transition from one phase to another phase of traffic might be more complex thing. This argument is supported by the following section on the driver reaction time. In addition, a more accurate prediction of driver behaviour particularly with respect to traffic conditions and type of vehicles may lead to a better understanding of mixed traffic systems. Towards this direction, the present paper gives a lead to the next generation traffic flow modelling approach particularly for mixed traffic conditions.

DRIVER REACTION TIME

Reaction time is a common phenomenon observed in driver operation and control of a vehicle. Driver reaction time can be described as the sum of perception time and the response by earlier car-following model based models [1]. In psychological studies, the driver reaction process is represented in four states: perception, recognition, decision, and physical response. In microscopic traffic simulation, the driver and vehicle are normally modeled as an integrated unit and the delay within the mechanical system of the vehicle is often neglected [2]. The reaction of driver affects the traffic dynamics not only in a microscopic way but also macroscopically [3]. Many studies have estimated the reaction time based on field experiments and driving simulators. A brief summary of the reaction times from various studies is presented in Table 1. In this table, the reaction time observed in the present research work is estimated from the Global Positioning System (GPS) data obtained through a series of experiments conducted on eastern express highway in Mumbai, India. More details about the experimental procedure and the data analysis can be obtained from the recent study [4]. It can be observed a wide variation in drivers' reaction times over the number of studies conducted. This suggests that variation in driving behaviour across the countries and in different traffic conditions. The other complex thing to model the traffic flow behaviour is the question of lane or non-lane based, which is described in the next section.

Table 1: *Comparison of Driver Reaction Time from Various Studies.*

Experiment	Reaction time (s)	References
Pedal experiment	0.4 to 2.7	[6]
Stopping Sight Distance	Unexpected stimuli: 1.3 Expected stimuli: 0.7	[7]
Model calibration	1.34	[8]
Field car-following data	1.27 to 1.55	[9]
Driving Simulator	anticipated danger: mean: 0.42 and standard deviation: 0.14 unanticipated danger; mean: 1.1 and standard deviation:0.72	[10]
Field car-following data	0.52 to 1.24	[2]
Vehicle trajectory data (NGSIM)	0.86 and s.d. 0.76	[11]
Model calibration from GPS field data	1.32 to 3.87	[4]

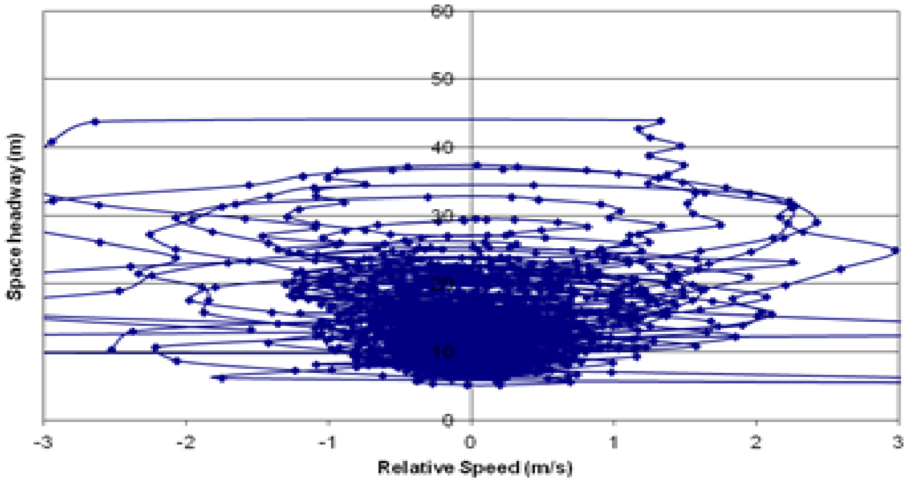
LANE AND NON-LANE BASED

The fundamental premise of many of the widely used traffic simulation models is based on lane oriented concept. Few attempts were made to model non-lane based traffic and a brief review of those is presented below. A modelling approach for mixed traffic streams with non-motorized vehicles is proposed by [5]. Their model was capable of considering various vehicle types, including motorcycles, bicycles, and three-wheeled vehicles, and even pedestrian-pulled carts in major streets with faster traffic. The model considered the performance capabilities of various vehicle types and the nonconventional behaviour interactions. The model adopted a detailed lateral movement modelling approach in which both longitudinal and lateral motions of vehicles are considered. Departing from traditional approaches, in which all vehicle movements are restricted to a lane, the model considers overlaps between successive vehicles irrespective of their lateral position. However, the data used to test the model consisted of low presence of nonstandard vehicles and the results may vary for the traffic consisting of predominantly of such vehicle-types.

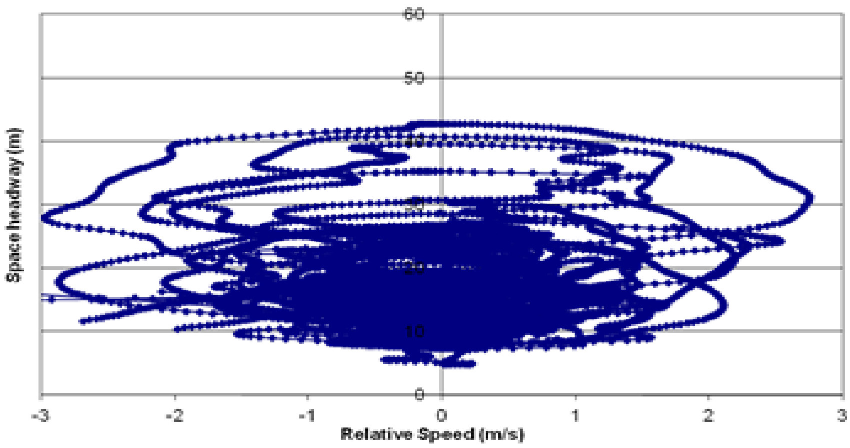
A computer simulation model of mixed motor vehicle and bicycle traffic on an urban road network is developed by modelling of mixed bicycle and motor vehicle following for the representation of longitudinal interaction of vehicles [12]. Few studies used cellular-automata models for modelling mixed traffic flow [13]. The famous NaSch cellular automata (NCA) model for motorized vehicles and the Burgur cellular automata (BCA) model for non-motorized vehicles are coupled to represent the interaction. The proposed model is named as the combined cellular automata (CCA) model. But their model was fundamentally based on the basic lane concept. The rationality of a non-lane based model is suggested by research work conducted modelling various types of vehicular interactions [14]. The subsequent works characterised the two dimensional aspects of headway [15]. However the modelling of non-lane based behaviour is still at a latent stage and needs much focus for a realistic representation of traffic conditions. Few recent contributions towards non-lane based vehicular model development are: CUTSiM (Comprehensive Unidirectional Traffic Simula tion Model) which find its use to simulate heterogeneous, uninterrupted traffic streams with or without lane discipline [16, 17]. Another recent effort resulted in the development of SiMTraM (Simulation of Mixed Traffic Mobility), a developed version of SUMO, a microscopic, space continuous and time discrete traffic simulation [18]. In SiMTram, a strip based model is used and a lateral movement model is adopted.

EFFECT OF VEHICLE-TYPE

To show the effect of vehicle-type, the relative distance and relative speed plots from a recent study [4] are depicted in Figure 1 for three vehicle-type combinations. It can be clearly observed that the closing behaviour is dependent on the vehicle-type and this behaviour is similar to the psycho-physical models being used in micro simulation tool VISSIM. The difference being: for smaller sized vehicles a close following behaviour is observed compared to other vehicle-type combinations. These studies show the effect of vehicle-type on following behaviour and the need for inclusion of vehicle-type in microscopic modelling technique.



Auto-rickshaw - Passenger car (A-C)



Passenger Car-Passenger Car (C-C)

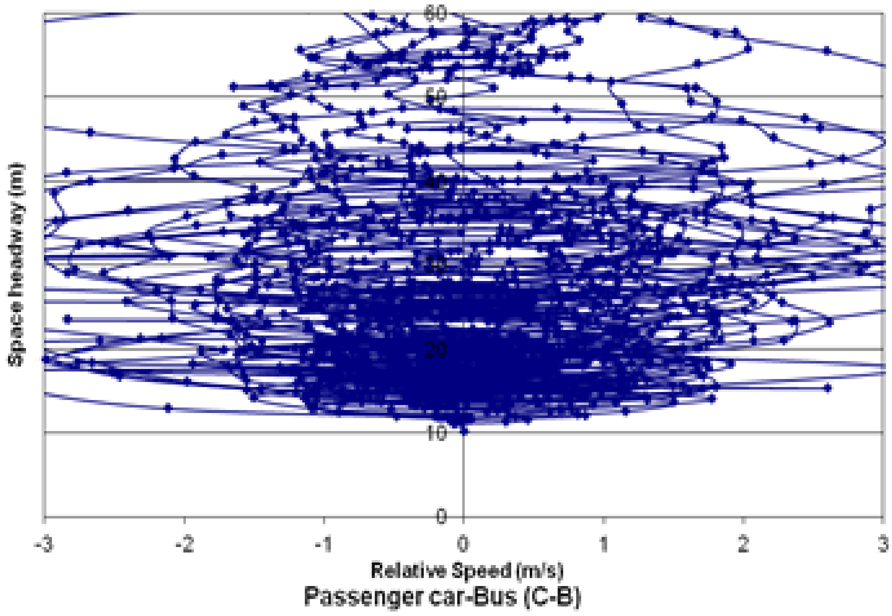


***Fig. 1:** Relative Speed and Relative Distance Plots for Various Vehicle-Type Combinations Showing the Closing and following Behavioral Differences.*

LATERAL BEHAVIOURAL MODELS

Another aspect of mixed traffic conditions is the lateral position of vehicles across the carriageway. A car-following theory with lateral discomfort is proposed by modifying the existing model to include lateral discomfort [19]. The model incorporated the effect of the lateral position of the following vehicle based on the off-centre effect of the lead vehicle. Their results showed a reduced following distance with increased lateral separation between the leader and follower vehicles. Another effort by the same researcher introduced a model which allowed speed for the following vehicle at the end of the reaction time is governed by speed at which the vehicle can decelerate to the maximum speed allowed by the width of this escape corridor and a speed which should allow the following vehicle adequate time to veer laterally so as to safely avoid a rear-end collision. Their research effort culminated in a non-lane based model in which the interaction between vehicle was modelled based on position of vehicle on the lane and the number of lead vehicles influencing the following vehicle. As described earlier, lateral movement models were used in SiMTraM and CUTSiM. These studies helped in understanding of non-lane based behaviour. The future research direction is going towards development of integrated models.

Small sized vehicles tend to occupy the space available between vehicles. The discipline of lane based driving can be examined from the lateral position of vehicles across the carriageway. Irregular distribution of traffic across the carriageway was the most important characteristic of weak lane discipline [19]. Data for lateral position of vehicles was extracted using screen super imposition method. In this method, a grid was drawn on a overhead transparency sheet and overlayed on the computer screen while the video was playing. The grid covers the length and width of the road over the selected stretch visible in the video. In order to analyse the lateral position of vehicles across the carriageway, the central position of vehicles were noted for different vehicle-types. These positions were noted for each of the median, middle, shoulder lanes, and the paved shoulders as the vehicles passed a particular reference line on the carriageway such that each lane is divided into five equal parts. Vehicles changing lanes were excluded from this analysis.

The lateral position of different vehicle-types across the carriageway is shown in Figure 2. It was found that passenger cars observed the lane discipline better than other vehicle-types. Also a normal distribution is observed in each of the lanes for the passenger cars. But three-wheeled auto-rickshaws were distributed across the lane width and are observed to move across the lane due to their smaller size. These typical characteristics of lateral position of vehicles across the carriageway effects the traffic flow in mixed traffic conditions.

LATERAL ARRIVAL PATTERN

The existence of lateral friction between vehicles is of special attention particularly in multilane highways. It was found that the arrival of vehicles across the road (laterally) is not random and lateral throughput in addition to the conventional longitudinal throughput [20]. The data was collected from eastern express highway in Mumbai in India, by means of video recording and manual analysis of video frames is done. The vehicular arrivals spatially are observed in a certain section of the highway and reference line is drawn in order to make sure that the observation point is noted. The readings were then recorded in the form of a table. These occupation and arrival patterns were observed very carefully. Readings were taken three times a minute by stopping the video at regular intervals, and hence each row of the table represents a separate condition. Rows were then distributed over a number of groups, the number of which is the all possible permutations of vehicle occupancy in the highway section. For example, for a three-lane carriageway, there are eight different possibilities of vehicle occupations in the selected highway section. Table 2 shows these conditions for the observed arrival patterns. The distribution of vehicular arrival probabilities over different arrival conditions in the study area is shown in the Figure 3. A preliminary observation of extracted data shows that vehicles tend to occupy a non-occupied lane more often than an occupied lane. Also the probability that vehicles occupy the outside lane or shoulder lane is less for all the conditions except for the non-occupied condition C5. This shows that irrespective of the static and dynamic characteristics of vehicles, vehicles tend to move in the faster lanes contrary to the practice of lane based behaviour in homogeneous traffic conditions.

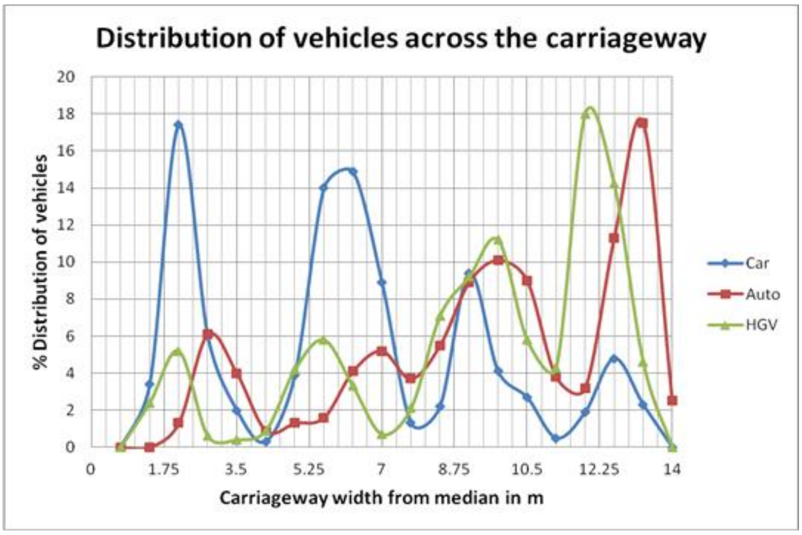


Fig. 2: *Lateral Distribution of Vehicles across Carriageway.*

Table 2: *Possible Conditions for Observed Lateral Arrival Patterns.*

Lane/Condition	C1	C2	C3	C4	C5	C6	C7	C8
	(Currently Occupied lane)							
Inside Lane	-	1	-	-	1	1	-	1
Middle Lane	-	-	1	-	1	-	1	1
Outside Lane	-	-	-	1	-	1	1	1

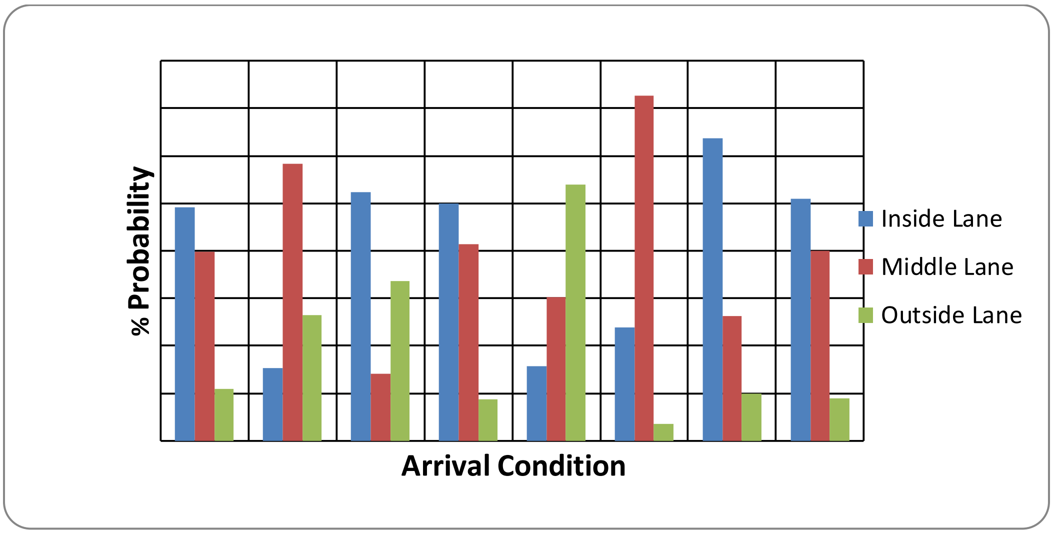


Fig. 3: *Probability of lateral Arrival Pattern Based on Conditions presented in Table 2.*

INTEGRATED MODELS

A recent effort in modelling is integrated models which try to combine the effect of one decision over another decision. Their model combined lane changing and acceleration decisions jointly, which captures inter-dependencies between the behaviours [21]. They formulated the drivers' choice of gap and target gap acceleration models. The results presented in their research work are based on a data collected in 1980s on a single section of the road and needs further testing and validation with recent data sets. A more comprehensive approach to integrated model development involving several of driving tasks is need of the hour. In the real driving situation, a driver has a multitude of tasks being executed. For example, observation on other vehicles and environment coupled with decisions on acceleration/deceleration behaviour. The inter-dependence among these decisions has to be clearly quantified for use in modelling. The other challenge is the use of Intelligent Transportation Systems (ITS) technologies and their effect on the driver decision making process. These integrated models may have the ability to realistically reflect driver behaviour and vehicular interactions and to model various levels of traffic from congested to uncongested conditions and their transitions.

CONCLUSION

Although some recent works take lateral movement into account for modelling mixed non-lane based traffic, the vehicular headway relationships are all same lane based or the fundamental premise in these modes is based on certain following theory. A comprehensive model capturing the different driving behaviour and integration of complex driving task decisions is in much need. Future research should focus on integration of longitudinal and lateral placement of vehicles and inclusion of transition regimes. Future studies should try to quantify the effect of composition of traffic on the discipline of lane based driving.

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