

ANALYSIS OF LATERAL DISTANCE KEEPING BEHAVIOUR IN MIXED TRAFFIC CONDITIONS WITH LITTLE LANE DISCIPLINE

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Abstract: Lateral distribution of vehicles across the carriageway was the most important characteristic of traffic with little lane discipline. The absence of lane behaviour implies that a driver not only interacts longitudinally with the vehicles ahead but also laterally with vehicles on its sides. The discipline of lane based driving can be examined from the lateral position of vehicles across the carriageway. An analysis of lane changing behaviour indicates characteristic differences in lane changing for distinct vehicle-types. In this study, an attempt is made to understand non-lane based behaviour of traffic in which lateral distance keeping behaviour, lane keeping behaviour and lateral behaviour of vehicles are studied. The effect of traffic composition on lane wise headway behaviour of vehicles is studied. 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. Lateral clearances of various vehicle-types are also compared in this study.

Keywords: Mixed traffic; lane discipline; lateral discomfort; lane changing; lateral behaviour.

1. Introduction

Headway is defined as the time interval between successive vehicles from a reference point of the first vehicle to the same reference point of the second vehicle as they pass a point along the lane. The time headway between the vehicles is an important characteristic of traffic flow which affects the safety of vehicles and capacity of the transportation system. Car-following theory is based on the concept that the action of a vehicle on the road is governed by the actions of one or more vehicles immediately preceding it. Factors influencing the interaction between vehicles include relative position and speed

with respect to the lead vehicle, length of the lead vehicle, acceleration of vehicles, and perception-reaction time of the follower.

Lane changing behaviour is much more complex in mixed traffic conditions, where the vehicle and driver behaviour show an enormous distinction compared to homogeneous traffic conditions. During a lane changing manoeuvre, small sized vehicles can be easily manoeuvred and tend to change lanes using smaller gaps. The lane change duration and the space gaps required for lane changing may also depend on vehicle-type dependent characteristics. Lane-based driving discipline can be

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defined as the tendency to drive within a lane by keeping to the centre as closely as possible unless in lane changing. One of the key assumptions of the single-lane car-following theory states that vehicles travel in the middle of the lane and each vehicle is influenced directly by the one in front. Vehicles position themselves laterally within their lanes according to a normal distribution and this bell-shaped distribution loses its normality in places where lane-based driving discipline is poor. Irregular distribution of traffic across the carriageway was the most important characteristic of little lane discipline.

Non-lane based movement is an indication of little lane discipline of vehicles which is predominant in mixed traffic conditions. A study on non-lane based behaviour of mixed traffic and the development of suitable models to represent this typical behaviour will be of much practical importance. The absence of lane behaviour implies that a driver not only interacts longitudinally with the vehicles ahead but also laterally with vehicles on its sides. Irregular distribution of traffic across the carriageway was the most important characteristic of little lane discipline and hence there is a need to analyse the effect of composition of traffic on lane based behaviour. The present study is intended to study the effect of traffic composition on lane wise headway behaviour of the vehicles, to study the lane changing behaviour and lateral behaviour of different vehicle-types in traffic conditions having little lane discipline. A brief review of the literature on the attempts to identify and model the mixed traffic behaviour with little lane discipline is presented in the following section.

2. Literature Review

Gunay and Erdemir (2010) investigated the two dimensional time headways in multilane traffic flow modelling. Existing car following theories assume that each vehicle is influenced directly by the one in front which is true only where lane discipline is extremely ideal and lanes are very wide. Santel (2010) provided a scientific base for the derivation of reference values for the range of lateral movements in road traffic and this is regarded as the amplitude of a vehicle trajectory on a straight track section.

The reasons for the weak discipline of lane based driving are different driving attitudes, poor road surface, poorly maintained lane markings and the non-existence of studs on lane lines which leads to loss of safety, difficult traffic management, inapplicability of conventional lane-based models (Gunay, 2004). A car following model with particular reference to weak discipline of lane-based driving was developed which was based on the discomfort caused by lateral friction between vehicles (Gunay, 2007). The movement of the following vehicle was formulated as a function of the off-centre effects of its leader. Choudhury et al. (2008) presented an integrated lane-changing model which allows drivers to jointly consider mandatory and discretionary considerations. Parameters of the model are estimated using detailed vehicle trajectory data. The lane-changing model is an important component within microscopic traffic simulation tools and this behavior is also important in several other applications such as capacity analysis and safety studies.

Gunay and Erdemir (2011) found that the vehicles will prefer to lag behind or lead ahead of the neighbouring vehicle until the flow is high. When the headway with respect to the front vehicle is less it cannot accelerate and also in a condition of higher density vehicles are forced to move side by side. An attempt to mimic multilane traffic flow for better microscopic modelling was done by the authors. Jin et al. (2011) modified time of collision equation with visual angle information and was introduced to the General Motors model. Visual angle information takes into account the lateral separation characteristics between the follower and leader. The suggested model was checked with simulations done under different driving scenarios. The model could describe local and asymptotic stabilities, lateral movement, the effect of neighbouring vehicles and the complex behaviour like partial lane changing.

Maurya (2011), developed comprehensive microscopic simulation model for uninterrupted unidirectional traffic stream which was able to determine both steering control as well as speed control actions of driver. Lateral control was described by goodness of path and longitudinal control by the acceleration of following vehicle. The model was evaluated using microscopic and macroscopic features such as acceleration noise, speed distribution, flow density and effect of road blockage on capacity. The model was validated with field data and it was able to simulate realistically the behaviour of traffic streams on wide roads without lane discipline. The input to predict following behaviour was safe distance headway, relative velocity, relative position and relative acceleration of lead and following vehicles. Sreekumar and Maurya (2012) identified the need for incorporating the no lane discipline

and the heterogeneity into the model and developed CUTSiM (Comprehensive Unidirectional Traffic Simulation Model). CUTSiM is used to simulate single lane traffic streams as well as traffic streams on wide roads with and without lane discipline.

Mahapatra and Maurya (2013) investigated the relationship between the vehicle longitude speeds with the lateral characteristics in the Indian traffic condition. The main purpose of their study was to observe the lateral acceleration, speed values in the moderate traffic conditions. There exists an inverse relation between longitudinal speed and lateral acceleration for all the three types of vehicle considered except at lower speeds. The vehicles rate of change of heading angle also reduces at higher speed. Metkari et al. (2013) clubbed the two models inspired by the Gipp's model, one covering the aspect of weak lane discipline and another, the vehicle type dependent behaviour. The study was conducted for uninterrupted unidirectional traffic on straight and level mid-block section in Delhi. Mathew et al. (2014) studied the weak lane discipline by dividing the lanes into small strips or bands and tracking the vehicle movement along them. Strip size is fixed according to the smallest vehicle being simulated. The lateral movement model calculates the benefit in making the lane change based on which whether decision for lane change is taken. If there is no change in lane then it will have a normal following behaviour.

The concept of the subject vehicle being influenced by those directly in the front and happens in a real traffic condition where lane discipline is ideal. Considerable amount of drivers prefers to lag behind the vehicle rather than to drive side by side. However, in mixed

traffic conditions with little lane discipline, drivers interact both longitudinally and laterally. The existing models have certain limitations in considering the factors such as lateral headway, vehicle type. Some attempts were made to model lateral clearance (Gunay, 2007) and influence of vehicle type (Ravishankar and Mathew, 2011). The vehicle type and lateral separation between the following and leader(s) vehicle are likely to influence the following behaviour. The lateral distance keeping behaviour and its influence on the lane keeping behaviour is yet to be fully understood and the present study paves the way for a more understanding of mixed traffic with little lane discipline.

3. Data Collection

Data was collected using a video graphic survey on an urban road section in Mumbai, India. Data was collected for a total period of 6 hours and 30 minutes. Video camera was kept over a foot over bridge at a height of 5.8 m from road level. This section is free from any intersections and the weather was clear with good visibility during the data collection periods. Camera position is fixed

in such a way that the vehicle lane changes can be observed and there is minimum interference to the driver behaviour.

Various parameters related to non-lane based driving discipline are extracted from the collected video. Typical mixed traffic consist of vehicles like cars, two wheelers, three wheeled auto-rickshaws, light commercial vehicles, buses and trucks. Headway behaviour of vehicles is analysed to make a note on longitudinal distance keeping behaviour of vehicles. The traffic data collected in the study area comprised of various modes such as cars, two wheelers (2W), three wheeled auto-rickshaws, light commercial vehicles, heavy commercial vehicles (HCV includes buses and trucks). The study area is a three-lane express highway section in which the traffic composition is noted lane wise. The traffic composition of various modes in the median, middle and shoulder lanes is shown in Fig. 1, 2 and 3 respectively. It can be observed that passenger cars occupied the median lane compared to the other two lanes whereas two wheelers tend to occupy the shoulder lane.

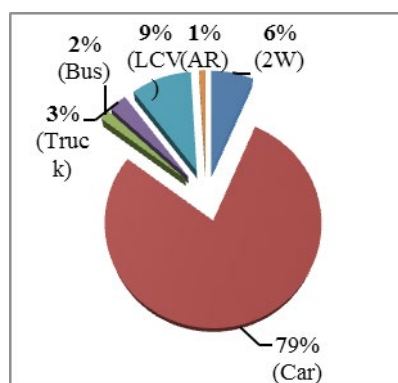


Fig. 1.
Traffic Composition of Median Lane

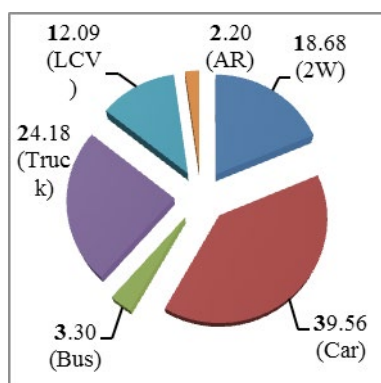


Fig. 2.
Traffic Composition of Middle Lane

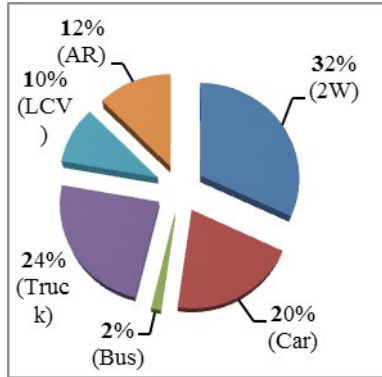


Fig. 3.
Traffic Composition of Shoulder Lane

4. Headway Behaviour

Headway observations are made lane-wise on each of the three lanes in order to study the effect of traffic composition on the longitudinal spacing of vehicles. The collected video data was played in the laboratory for extraction of headway data and vehicle composition. A careful examination

of the details of headway data sets collected revealed that adopting uniform headway class intervals for all the three lanes was not appropriate, as there was a wide variation in the range of observations. From the observed data, the average headway of the vehicles across median, middle and shoulder lanes is shown in Table 1. There is a clear distinction in the mean headway across the lanes.

Table 1
Average Headways Across Various Lanes

Lane	Average Headway (sec.)
Median	2.96
Middle	3.22
Shoulder	4.28

Headway distribution across the median, middle and shoulder lane are shown in Fig. 4, 5 and 6 respectively. Fig. 7 shows the percentage observed frequency distribution of headway across median, middle and

shoulder lanes. The observed and predicted probabilities of median and middle lanes are having considerable variation compared to shoulder lane which can be observed from the plots.

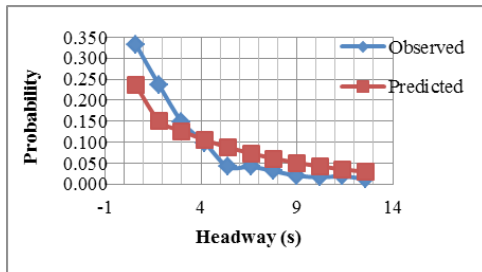


Fig. 4.
Headway Probability Distribution Across Middle Lane

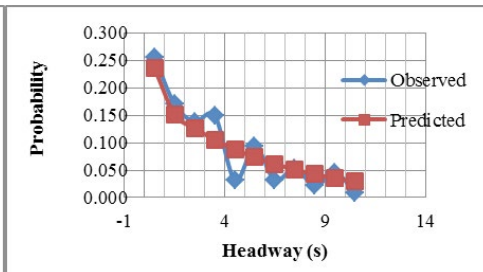


Fig. 5.
Headway Probability Distribution Across Median Lane

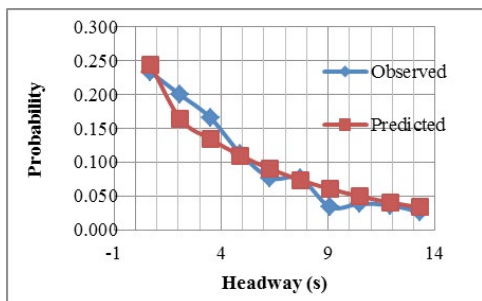


Fig. 6.
Headway Probability Distribution Across Shoulder Lane

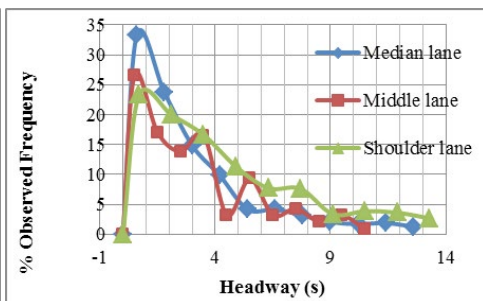


Fig. 7.
Headway Distribution Across Lanes With % Observed Frequency

The median lane is having shorter headways followed by middle and the shoulder lanes. It is observed that median lane having higher composition of cars of almost 79% constitutes shorter headway comparatively. As the car composition decreasing towards the shoulder lane, the average headways are increasing towards the shoulder lane. As the two-wheeler composition increasing towards the shoulder lane, the average headways are also increasing towards the shoulder lane. This indicates that the composition of these two modes have significant impact on the headway behaviour.

5. Gap Acceptance Behaviour

The gap acceptance behaviour determines the decision to accept or reject available gap in the lane changing modelling decision framework. In case the gap available is more than critical gap, then the lane change was executed. In this study, the gap accepted before the lane change initiation were critically examined to determine the variables like heavy vehicle influence and relative speed on the gap acceptance behaviour. The summary statistics of relative speed and spacing between the subject vehicle and front

vehicle and between the lead and lag vehicles is presented in Table 2. For cars, mean value

of relative speed with front vehicle is higher compared to other vehicles.

Table 2

Summary Statistics of Gap Acceptance Behaviour

Subject vehicle	Front vehicle relative speed (m/s)	Front vehicle relative spacing (m)	Lag-Lead vehicle relative speed (m/s)	Lag-Lead vehicle spacing (m)
	Mean (s.d.)	Mean (s.d.)	Mean (s.d.)	Mean (s.d.)
Car	3.97 (1.02)	13.86 (4.38)	2.86 (1.87)	21.53 (6.51)
Auto-rickshaw (AR)	2.69 (2.32)	8.35 (2.98)	4.12 (2.67)	15.39 (4.07)
HCV	2.91 (0.97)	15.28 (12.35)	1.57 (1.48)	31.24 (8.92)

Note: HCV: Heavy Commercial Vehicle, s.d.: Standard deviation

This may be due to the higher acceleration capability of cars trying to change lanes for better driving conditions. Mean values of front vehicle spacing and lag-lead vehicle spacing are less for auto-rickshaws. This may be attributed to the fact that these vehicle tend to change lanes in shorter gaps due to their inherent characteristics of higher manoeuvrability and lesser size. However, mean lag-lead relative speed is quite high for auto-rickshaws compared to other vehicles, which shows the extra caution adopted by the lead and lag vehicle drivers in the lane changing situation involving these type of vehicles.

6. Lane Change Characteristics

Lane changes have a significant impact on the characteristics of traffic flow. Existing models of lane changing behaviour concentrated on the decision-making aspects of the task and model the behaviour as an instantaneous event (Ramanujam, 2007). The acceleration behaviour of the vehicle

changing lanes and of other vehicles around may affect the duration of lane changes. It was also observed that mean duration of lane changes for high commercial vehicles is higher compared to cars and auto rickshaws. Hence in this study, lane change duration is also analysed to get a quantitative representation of difference across various vehicle-types. The summary statistics of lane change duration for the three vehicle-types is shown in Table 3. The mean lane change duration for car is quite less comparatively.

One of the possible reasons may be due to the higher acceleration capability of cars, drivers were able to complete the lane change in a much shorter time. However, heavy vehicle drivers have to manoeuvre their vehicles carefully and require higher duration. The standard deviation values suggest that the variability is higher for the car drivers. Also there is a wider variability in lane change duration across different vehicle-types and these values were comparatively higher for cars.

Table 3

Summary Characteristics of Lane Change (sec.)

Vehicle type	Mean (s.d.)
Car	5.06 (4.74)
Auto rickshaw	5.60 (3.71)
Heavy Commercial Vehicle	8.00 (4.39)

6.1. Lane Change Duration Probability

The distribution of lane change durations for the different vehicle-types is shown in Fig 8. The mean values of lane change duration for different vehicle-types suggest that heavy commercial vehicles require higher duration of time compared to other vehicles for completing the lane changing process. Due to the restricted view of the drivers in heavy commercial vehicles, they are more selective in changing lane and tend to change lanes less frequently comparatively.

Of all the vehicle types, cars require less duration of time comparatively for lane change. Because of attaining of high speeds, cars will change lanes frequently with less duration. The lane change duration for different vehicle types is spread across a wide range of time (2-16 seconds) and is

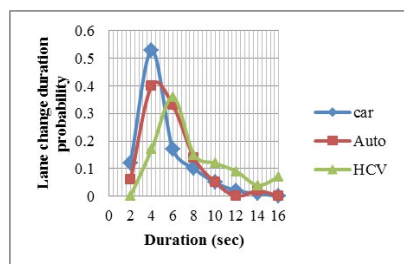


Fig. 8.
Distribution of Lane Change Duration of Various Vehicle Types

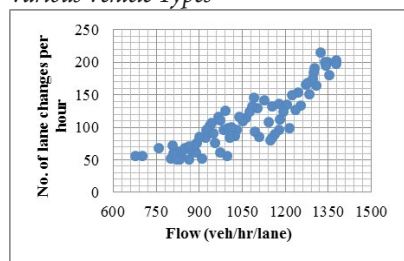


Fig. 10.
Variation of Number of Lane Changes With Flow

vehicle-type specific. This characteristic difference in lane change duration has to be properly included in future development of simulation models.

6.2. Lane Changing Frequency

The lane changing frequency is studied for different traffic flow parameters like flow, speed and density. The relation between traffic flow parameters and number of lane changes is analysed. The variation of number of lanes changes with traffic flow, density, and mean stream speed is as shown in Fig 9, 10 and 11 respectively. However it was observed that as the density increases, the tendency to change lanes decreased. It was observed from the results as the flow increases, the tendency to change lanes increased. It can be observed that as the mean speed increases, the tendency to change lanes increased.

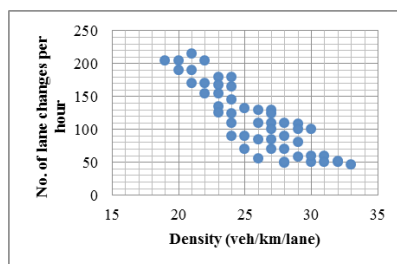


Fig. 9.
Variation of Number of Lane Changes With Density

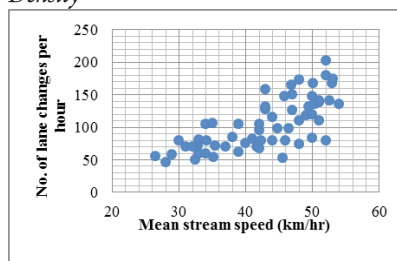


Fig. 11.
Variation of Number of Lane Changes With Mean Stream Speed

6.3. Lateral Behaviour

The lateral behaviour of the traffic is the most important aspect in having an idea related to lane discipline of vehicles. In this study, the lateral clearance between vehicles which indicates the interaction between the moving traffic stream, the lateral position of vehicles across the carriageway and vehicular lateral pattern are studied. Any vehicle moving in a traffic stream has to maintain sufficient transverse clearances on both sides with respect to other vehicles/curb/median to avoid side friction. Lateral clearance of the vehicle is based on the speed of that vehicle, speed of the adjacent vehicle and also their respective types. This lateral clearance is an important parameter for overtaking manoeuvre. Lateral clearances were adopted from the studies of Arasan and Arkatkar (2011) and these studies indicated the linear relationship of lateral clearances with speed and also given the minimum

and maximum limits for lateral clearances corresponding to a zero speed and 60 km/h speed condition respectively. The lateral clearance of different types of vehicles was calculated as per the following equation 1 (Gowri, 2011).

$$C = \frac{C_{\max} - C_{\min}}{V_{\max} - V_{\min}} (V_c - V_{\min}) + C_{\min} \quad (1)$$

where, C is the lateral clearance; C_{\min} is the minimum clearance, C_{\max} is the maximum clearance; V_c is the current speed; V_{\min} is the minimum speed; V_{\max} is the maximum speed.

Lateral clearance allowance is the clearance share pertaining to a vehicle type. The clearance value is assumed to vary linearly from minimum to maximum depending upon the speed of vehicles. The minimum and maximum lateral clearances for car with different vehicles types are shown in Table 4 for various vehicle-types.

Table 4

Minimum and Maximum Lateral Clearance for Different Vehicles With Other Vehicle-Types

Vehicle type	HCV		Car		Auto-rickshaw		Two-wheeler	
	C_{\min}	C_{\max}	C_{\min}	C_{\max}	C_{\min}	C_{\max}	C_{\min}	C_{\max}
HCV	0.6	1.2	0.6	1.1	0.5	1.0	0.4	0.9
Car	0.6	1.1	0.6	1.0	0.5	0.9	0.4	0.8
Auto-rickshaw	0.5	1.0	0.5	0.9	0.4	0.8	0.3	0.7
Two-wheeler	0.4	0.9	0.4	0.8	0.3	0.7	0.2	0.6

Note: C_{\min} = Minimum lateral clearance, C_{\max} = Maximum lateral clearance.

The speeds of each vehicle type were calculated by the time taken to travel a stretch of known length. By using the speed data of the car and clearance limits of car with different vehicle-types, the lateral clearances for car with different vehicle types are calculated and are represented in Fig 12. Similarly, using the speed data and clearance limits of two-wheelers, HCV and auto rickshaw, the lateral clearances with

different vehicle types are calculated and are shown in Fig 13, 14 and 15 respectively.

From the results, it is observed that there exists a linear relationship between the lateral clearance and speed of different vehicle types. Lateral clearances are directly proportional to the size and speed of the vehicle. As the vehicle size is more, the lateral clearance to be maintained is high.

As the speed of the vehicle increases, the lateral clearance to be maintained with the

surrounding vehicle will also increase with regard to safety point of view.

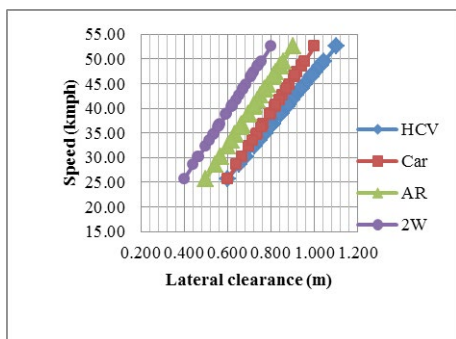


Fig. 12.
Lateral clearance for Car With Different Vehicles

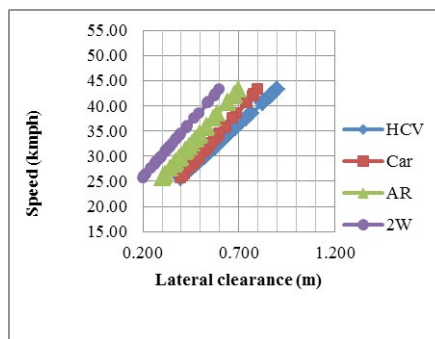


Fig. 13.
Lateral Clearance for Two-Wheeler With Different Vehicles

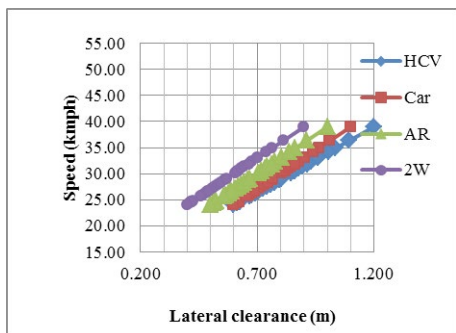


Fig. 14.
Lateral Clearance for HCV with Different Vehicles

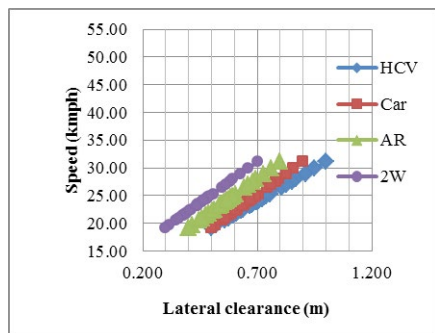


Fig. 15.
Lateral Clearance for Auto-Rickshaw With Different Vehicles

From the above mentioned figures, it is observed that two-wheelers are maintaining less lateral clearances compared to all other vehicle types at the same speed level due to their high manoeuvrability. Auto rickshaws are maintaining more lateral clearances at the same speed compared to other vehicle types followed by HCV and cars due to the extra caution taken during passing vehicles.

7. Lateral Position of Vehicles

The discipline of lane based driving can be examined from the lateral position of vehicles across the carriageway. Data for lateral position of vehicles was extracted using screen super imposition method. In this method, a grid was drawn on overhead transparency sheet and overlaid 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. Slower vehicles occupied the left

most lane and faster vehicles occupied the right most lane as expected. The lateral position of different vehicle-types across the carriageway is shown in Fig 16. It was found that cars observed the lane discipline better than other vehicle-types. Also a normal distribution is observed in each of the lanes for the 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.

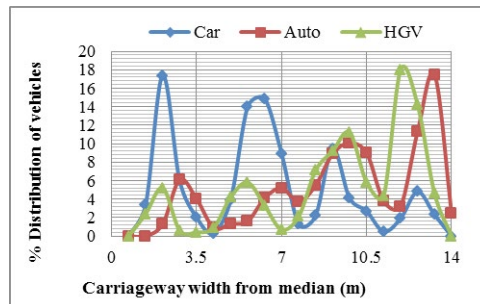


Fig. 16.
Lateral Position of Vehicles Across the Carriageway From Median

8. Lateral Arrival Pattern of Vehicles

The existence of lateral friction between vehicles travelling in unidirectional multilane highways attracted special interest in the past. 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. The number "1" in the table indicates the occupancy of vehicle in that lane. For example, for a three-lane carriageway, there are seven different possibilities of vehicle occupations in the selected highway section. Table 5 shows the percent analysis of the vehicular arrivals.

Without needing for significance tests, by visual inspection of the table form conditions C2 to

C7, it is possible to suggest that the probability of the next arrival on a lane that is already occupied by a preceding vehicle is less than

the probability of the next arrival on a non-occupied lane. This implies that lane by lane vehicular arrivals are not very independent.

Table 5
Observed Lateral Arrival Patterns on a Three-Lane Highway

Condition	Median lane	Middle lane	Shoulder lane	Probability (%) that the next vehicle arrives on the		
				Median lane	Middle lane	Shoulder lane
C1	-	-	-	49.16	39.85	10.99
C2	1	-	-	15.26	58.39	26.47
C3	-	1	-	52.36	14.03	33.61
C4	-	-	1	50.00	41.35	8.65
C5	1	1	-	15.73	30.34	53.93
C6	1	-	1	23.82	72.61	3.57
C7	-	1	1	63.77	26.28	9.95
C8	1	1	1	50.99	40.03	8.98

9. Conclusions

The median lane is having shorter headways compared to the middle and shoulder lanes. As the car composition decreasing towards the shoulder lane, the average headways are increasing towards the shoulder lane. As the two-wheeler composition increasing towards the shoulder lane, the average headways are also increasing towards the shoulder lane. This indicates that the composition of these two modes have significant impact on the headway behaviour of vehicles. Heavy vehicles are observed to take longer durations compared to small sized vehicles like three wheeled auto-rickshaw and cars. Small sized vehicles tend to change lanes using shorter gaps, possibly due to the high manoeuvrability of these vehicles. Lane change duration is found to be significantly different for various vehicle-types. Lane changing frequency is influence by the density, flow and mean speed of the traffic stream. Two-wheelers are maintaining less lateral clearances compared to all other vehicle types at the same speed level due to their high manoeuvrability.

Distribution of the lateral position of vehicles across the carriageway shows that cars have better lane discipline than other vehicle-types. The probability of the next arrival on a lane that is already occupied by a preceding vehicle is less than the probability of the next arrival on a non-occupied lane and this implies that lane by lane vehicular arrivals are not very independent.

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