# Study on Lateral Placement and Speed of Vehicles under Mixed Traffic Condition

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**Abstract**: In India, due to absence of lane behavior, vehicles not only interact longitudinally but also interact laterally with the vehicles around it. Road features like road edges, divider, electric poles, raised footpaths, etc. also affects the vehicle's movement and its lateral placement. Vehicles maintain certain clearance from an object/road element that they perceive as obstacle. For detail understanding of complex traffic behavior and evaluation, a detailed microscopic simulation model is needed. Vehicular speed and time headway are the important inputs of such simulation model. In the present study, impact of different lane positions (Median Lane, ML and Shoulder Lane, SL) has been analyzed for a 4 lanes, 6 lane and 8 lane divided highways on average travel speed, Time headway and lateral clearances. A sensor assembly consists of two ultrasonic sensors placed alongside the road at known distance with a camera is developed to measure Lateral clearance and Vehicle's speed.

*Keywords*: No-Lane Disciplined, Shoulder Lane, Median Lane, Lateral Clearance, Lateral Gap, Speed, Time Headway

## 1. INTRODUCTION

In India, due to no-lane discipline and mixed traffic condition, the lateral movements of vehicles are high in comparison to vehicles in lane-disciplined traffic of developed countries. In absence of lane behavior, vehicles not only interact longitudinally but also interact laterally with the vehicles around it. Road features/elements (like road edges, divider, electric poles, raised footpaths, etc.) also affects the vehicle's movement and its lateral placement depending upon whether drivers perceive a roadside element as an obstacle or not. Vehicles will move away (or maintains certain clearance) from an object/road elements that they perceive as obstacle. The clearances maintained by vehicles depend on their vehicle type and speed. Vehicles may require to maintain higher clearances at higher speed. According to Highway capacity manual, lane position is crucial to traffic performance in multilane highways. This is due to diverse effects of lanes on driver's behavior and traffic flow. Generally, heavy and slow vehicles move in left lanes because of low speed and partially due to prohibition on using right lanes (assuming left traffic regulation). In multilane traffic, distribution of lane use depends on vehicle's size and operating characteristics. Lane volume distribution depends on vehicle mix, traffic regulations, speed, destination patterns and drivers' habits. Hence, there is no standard lane distribution. Further, traffic composition in India includes widely varying vehicles in terms of their size and operating characteristics. Also, with the rapid growth in number of vehicles, issues like congestion, air and noise pollution are prevalent in most of the urban areas. For detail understanding of complex traffic behavior and evaluation of different congestion management strategy, a detailed microscopic simulation model is needed. Development of this model requires a comprehensive understanding of microscopic and macroscopic parameters. Vehicular speed and time headway are the important inputs to the development of such simulation model.

In present study, impact of different lane positions (Median Lane, ML and Shoulder Lane, SL) has been analyzed for 4 lanes and 6 lane and 8 lane divided highways on average travel speed. Time headway and lateral clearances. Statistical analysis has been carried out to see the vehicle composition effect on lane specific speed, time headway and the lateral clearance characteristics. Data has been collected on straight mid-block sections of one 4 lanes and one 6 lane and one 8 lane divided highways with different traffic compositions. A sensor assembly consists of two ultrasonic sensors placed alongside the road at known distance with a camera is developed to measure (i) Lateral clearance maintained by vehicles from road elements (ii) Vehicle's speed traveling near edge lane (ML/SL). Operation of this assembly is semi-automatic with little intervention.

Literature review yields limited studies related to interaction of vehicles with various road elements like road edges, medians, kerb, roadside environments, etc. Data collection (like, speed, volume, vehicle's lateral position, etc.) in such studies conducted in developed countries generally uses methods like video recording, use of piezoelectric sensors, pressure sensitive electrical tape switches, etc. These methods do not measure lateral placement of vehicles directly. Some other studies regarding the on-road guidance systems and road furniture are carried out on driving simulator. No matter how large the simulator motion system is, it will not be feasible to provide the continued lateral acceleration that a driver would feel in real world negotiation of a long curve. There are very less studies conducted in real traffic streams. Hence studies like this are very important in developing countries like India due to their heterogeneous and mixed traffic condition, for development of a better realistic traffic simulation model.

## 2. OBJECTIVE

The main objective of this research work is to study the vehicles lateral and longitudinal movement in the Indian heterogeneous non-lane disciplined traffic condition and also the impact of traffic composition, lane distribution etc. on traffic parameters like vehicular speed, time headway and lateral placement of vehicles. The detailed objective is as given bellow.

1) To study the Impact of Speed on the Lateral Placement of vehicles
2) Impact of Lane distribution on the vehicular speed.
3) Impact of lane distribution on the Time headway.

## 3. BACKGROUND

Various studies had been conducted in the past regarding the lateral behavior or the lateral placement of the vehicles on the multilane highways. The following are the few literature studies has been described here. The total study is divided in different parts.

1. Impact of road side features on the lateral placement of vehicles and vehicular speed.
2. Impact of Traffic parameters on the lateral behavior of vehicles.
3. Impact of Lane distribution on the vehicular speed.
4. Impact of lane distribution on the Time headway.

### 3.1 Impact of Road Side Features on the Lateral Placement of Vehicles and Vehicular Speed

Thiffault and Bergeron (2003) have done a simulator study on the Monotony of road environment and driver fatigue. Driving performance on a driving simulator is closely analyzed on two different monotonous road conditions, each characterized by a different visual scenery. The result suggest that, road side visual simulation have an impact on driving fatigue and may built up drowsiness when driving on highly repetitive road environment. Richard and Selma (2007), studied the influence of roadside infrastructure on driving behavior. They concluded that, Independent of the presence or absence of an emergency lane, the type of barrier or guard rail introduced does not have an effect on speed. The effect on speed is only present where trees are positioned 2m away from the roadside and with a guardrail positioned in front of these trees. One important result from this study was that after the trees have been cut down, the average number of accidents was halved, and the number of fatal accidents reduced by a factor of four. Hence, it is important to realize that the current guidelines recommended that no obstacles should be in the safety zone which is at least 4.5m from the lane edge for 80km/h roads in most European countries. Again Antonson et al. (2009), Peng et al. (2012), and Francesco Bella (2013), also studied on the effect of surrounding landscape and road side features on driving behavior. The effect of roadside configuration on the lateral position (movement towards the center of the road), suggest that placing the beginning of the guard rail on left curves should be avoided.

Cornelie et.al. (2004), done a meta-analysis on the effect of edge line on speed and lateral position. The studies included in the meta-analysis were retrieved by means of a systematic literature survey. It was found that, applying an edge line to a road in combination with shoulder width, road environment, and presence or absence of a centerline influences speed and lateral position of motorized road user. Application of an edge line to a road can lead to a decrease in speed of the motorized road users, but application of an edge line without a centerline can increase the speed of the motorized road users. Further, it was concluded that the lateral position more towards the edge of the road is related to wide shoulders and reversely. Porter et.al. (2004), also studied on the evaluations of effects of centerline rumble strips (CRS) on Lateral vehicle placement and speed. To collect lateral vehicle placement and speed data within single lane, four tape switches were placed in the travelled path. Tape switches are simple, pressure sensitive electrical switches with an equilibrium mode in the off position. The application of force to the tape switch compresses the exposed deformable material, causing contact between conductors and completing the circuit. A video recorder was used with its clock display synchronized to the time on the data logger. The result of field data collection showed that, there exists a significant variation in lateral placement of the vehicles after the rumble strips installation. The lateral placement increases from 2 in. and 3 in. to 5.5 ft. and 3 ft. for 12 ft. and 11 ft. roads respectively. Again Michael et al. (2006), and Melish D. (2006) studied the evaluation of operational impacts of installation of centerline and edge line rumble strips. The CRSs resulted in an increase in vehicle separation. It is concluded that SRS offset further away from the edge line have less of an impact on the lateral placement of vehicles in the travel lane. Yang et al. (2013), studied on the effect of curbs on driver behavior in four-lane rural highways. It is found that, speed is not affected by driver ability to see distances, but rather by the heterogeneity of surrounding areas. The findings of this paper is that the surrounding landscape affects driving behavior.

### 3.2 Impact of Traffic Parameters on the Lateral Behavior of Vehicles

Ritchie et al. (1968) conducted a study on relation between longitudinal velocity and lateral acceleration in curves during normal driving. For speeds above 20mph there exists a strong inverse relation between the velocity and lateral acceleration of vehicles. Tamiya et al. (1996), suggested an Optical spread spectrum radar for lateral detection in vehicles. Dey et al. (2005) established a study on lateral distribution of mixed traffic on two-lane roads. . The difference between 90$^{th}$ percentile and 10$^{th}$ percentile placement is defined as the variation in placement. Again Dey et al. (2006) studied on the lateral placement of vehicles under mixed traffic conditions. Slow moving vehicles travel near the edge of the road whereas fast moving vehicles have the tendencies to travel near the centerline of the road. So, the distribution of placement of vehicles depends upon the traffic composition and traffic volume both. Stodart and Donell (2008) conducted a study on the behavior of speed and lateral vehicle position in controlled night time driving condition. They found that, two variables (i.e. curve direction and horizontal curve radius) were found to have the largest association with the change in vehicle lane position. Shauna L. Hallmark (2009) conducted a study on the curve road section to find if any endogenous relationship exists between speed and lateral position of vehicles. Results statistically signify that vehicles at higher speeds had greater odds of near lane crossings. Balaji et al. (2013), conducted a study on lateral placement and speed of vehicles on two-lane roads. Result indicates that vehicular speed increases as the vehicle shifts towards the center of the road. The reason behind this is as the vehicles shifts towards the center of the road it is affected by the vehicles coming from opposite direction. The analysis shows that 3-wheelers, heavy vehicles and slow moving vehicles follow a linear relation while 2-wheelers and cars follow a second degree polynomial relation.

### 3.3 Impact of lane distribution on the Time headway

Tamiya et al. (1996), suggested an Optical spread spectrum radar for lateral detection in vehicles. The objective was to confirm whether the continuous distance measurement to the roadside guardrail was possible or not. But there are certain limitations of the radar based sensors; radar can sense a lot of these materials, but the energy of the returning waves is so small that precise alignment with the signal is paramount. This introduces techniques such as guided wave radar, or special antenna. Measuring materials with a low dielectric constant is not always impossible, just very challenging. The radar sensors are more costly. Teshima et al. (2006), also suggested a vehicle lateral position estimation method based on matching of top view images. The proposed method does not rely on extraction of features such as lines, flow vectors or lane markers, but based on matching of warped top-view images between two consecutive frames. Shauna L. Hallmark (2012) conducted a study on the curve road section to find if any endogenous relationship exists between speed and lateral position of vehicles. Data were collected by using Z configuration pneumatic road tubes. They followed the methodology used by Finley et al. (2009) and Porter et al. (2004) that uses pneumatic road tubes set up in a Z configuration. Jiann-Shiou Yang (2012) determined the vehicle heading angle by using image based technique via an in-vehicle camera.

In India there are very few studies has been conducted on the lateral behavior of the traffic. Dey et al. (2005 and 2006); studied on the lateral placement of vehicles under mixed traffic conditions. Again Balaji et al. (2013), conducted a study on lateral placement and speed of vehicles on two-lane roads. They also followed the same method as Dey et al. (2005, 2006). Data were collected by dividing the lane width into sections of 25 cm each with self-adhesive cloth tape and these were numbered seriatim from pavement edge to the center of road. The placement of left rear wheel of a vehicle crossing the section was recorded by video recording and analyzed manually to get the vehicles' lateral position. Accuracy of such approach of vehicle's lateral position measurement is always poor and questionable.

## 3.4 Motivation

The review of literature on lateral characteristics of vehicles revels that change in lateral position depends on various traffic parameters, road condition as well as the geometric condition of the road. Most of the studies has been carried out in developed countries with lane disciplined condition. But, due to no lane discipline and mixed traffic condition, in India the lateral movement of vehicles are high. Although the relationship between speed and lateral position is important in understanding curve negotiation, the relationship is not well understood. Numerous studies had been conducted using different methods and technologies to find the lateral position of vehicle on road. Most of the studies were limited to analysis of lateral movement of vehicle on curves. Studies related to vehicle's lateral characteristics on straight road with mixed and no lane-disciplined traffic were found important to understand the vehicle's lateral movement behaviour in a traffic stream for realistic traffic simulation model. Among the few studies carried out in India were based on limited data and manual data analysis. Therefore, accuracy of such results can always be challenged.

Hence this study is important for the realistic traffic flow model simulation, vehicle/driver behavior of the vehicles due to various traffic features like vehicles ahead, vehicles to the side, the mixed traffic condition, etc. Again, most of the studies were conducted on curved roads. Studies related to behavior of vehicles lateral position in no (or weak) lane disciplined traffic have not been found. Therefore, studies on vehicle's lateral movement on straight roads in Indian traffic streams needs to be conducted to analyze the weaving motion of vehicles in such traffic.

## 4. METHODOLOGY

The present study explores the association of lane specific speed characteristics of different types of vehicles on different Indian highways. As shown in Figure 1, a sensor based assembly had been developed to measure the lateral clearance maintained by different vehicles from road elements such as road edge, divider, footpaths, etc. Two ultrasonic sensors were placed along the side of the road at known distance (say D) as shown in Figure 1.

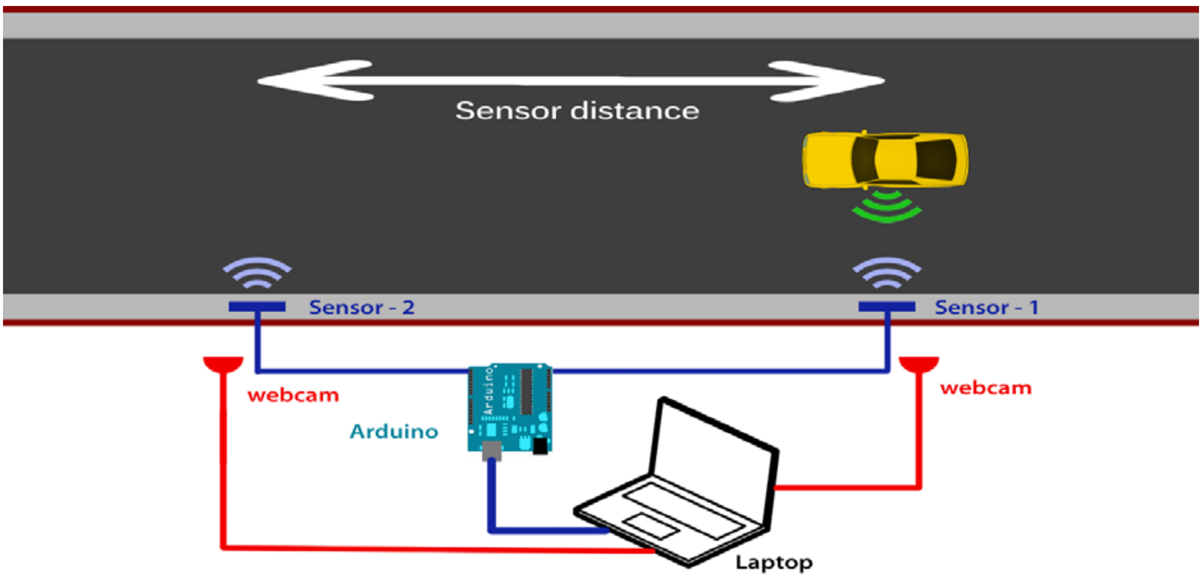


Figure 1 full sensor assembly layout on road

The operation of this assembly is described as follows. It is semi-automatic with very little human intervention. As a vehicle passes in front of Sensor 1, it gets activated and receives the reflected waves from the vehicle. Based on the travel time of emitted wave and reflected wave, there is a difference in time between the emitted wave and the received reflected wave. The lateral clearance of the vehicle from the sensor is calculated from this time difference. In a similar manner, the lateral clearance of the vehicle from Sensor 2 is also calculated. As the sensors are placed apart with a known distance D along the edge of the road, travel time of the vehicle for distance D is determined from the time difference of the actuation of both the sensors(the time difference between the times of receiving the reflected waves can also be used). Based on the measured travel time for the known distance D, the vehicle speed is calculated. Further, the sensor assembly also actuates the webcam to take a snapshot of the passing by vehicle for accurate vehicle type classification. All the data thus received or calculated, get stored in the attached Laptop as shown in the sensor assembly in Figure 2.

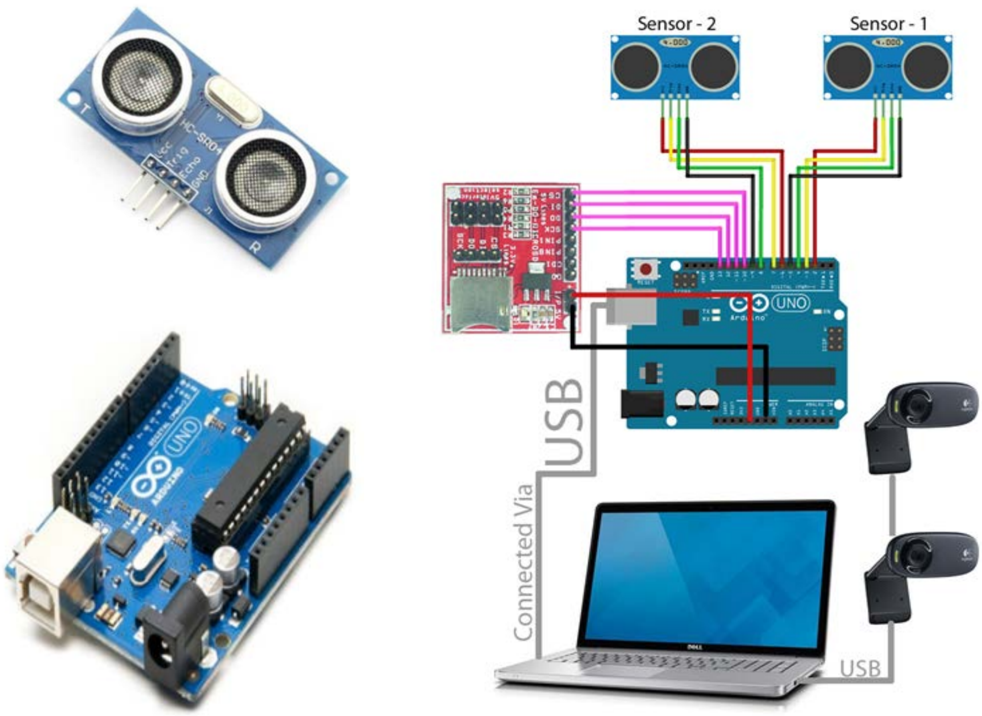



Figure 1 Sensor based assembly with full setup

The sensor assembly has been so designed that it measures the lateral clearances with an accuracy of ±5 cm. Thus, the developed assembly aids in measuring the following

1. The lateral clearance maintained by vehicles from road elements.
2. Speed of the vehicles for five different types of vehicles in the traffic mix such as Truck, Bus, Car, Three wheelers and motorized two wheelers etc.

This assembly helps in large scale data collection of the lateral clearances maintained by the vehicles from the road elements. Data was collected on straight mid-block sections of a 4 lane (NH-37), 6 lane (NH-8) and 8 lane (NH-1) divided highways with different traffic compositions. The impact of the different lane positions (such as the Median Lane, ML and Shoulder Lane, SL) has been analyzed for all sections on average travel speed. The lateral clearance of the each vehicle type from the SL/ML road marking is calculated. Data were collected on morning peak hours in December 2013 in sunny weather conditions. The road surfaces were in good condition with proper lane markings.

Speed, flow and vehicle composition of ML & SL of all highways are calculated from the field data. Lane specific average speed for each vehicle type on different roads are computed. A statistical analysis is done to see the difference in the lane specific speed characteristics of a particular vehicle type on different Indian roads. A MATLAB program is used to analyze the data. The speed and lateral clearance of each passing by vehicle is calculated with respect to the time and vehicle type. Hence, the speed and lateral clearance of each vehicle with respect to its vehicle type is analyzed for all the sections for the ML and SL.

## 5. RESULT AND ANALYSIS

The traffic data have been collected by the sensor assembly as mentioned in the above section. The total analysis is divided into the following categories. A comparative study is done between the 4 lane, 6 lane and 8 lane highways. The following few are the comparisons.

1. Lane specific Speed-Flow-Density diagrams of all the three types of highways with different traffic composition.
2. Lane specific speed and time headway distribution of all three highways
3. Percentile distribution of lateral gap w.r.t. vehicular speed
4. Lane Specific Lateral Gap variation w.r.t. the vehicular speed
5. Lane specific vehicle type wise Lateral Gap variation w.r.t. vehicular speed for all three type of highways.

### 5.1 Lane specific Speed-Flow-Density diagrams of all the three types of highways with different traffic composition

Traffic composition of all three types of highways are shown in Table 1. Speed, flow and density are the three basic parameters of a road. The Lane wise speed-flow-density diagrams of all three types (4 lane, 6 lane and 8 lane) highways are plotted. A comparative study is done for lane specific traffic behavior from those diagrams.

Table 1 Traffic composition of all three types of highways for ML/SL

| Vehicle type | Lane | Car | Truck | 2W | 3W | Bus |
|---|---|---|---|---|---|---|
| 4 lane highway | ML | 67.41 | 19.49 | 6.25 | 0.59 | 6.25 |
| | SL | 25.31 | 9.88 | 50.62 | 10.49 | 3.7 |
| 6 lane highway | ML | 95.8 | 0.69 | 3.38 | 0.12 | 0 |
| | SL | 16.89 | 16.58 | 60.03 | 3.62 | 2.87 |
| 8 lane highway | ML | 98.88 | 0 | 0 | 0 | 1.12 |
| | SL | 1.92 | 44.23 | 49.36 | 2.99 | 1.45 |

From Table 1 it is observed that all the three types of highways consists maximum percentage of car in ML and 2W and Truck in SL. Hence it can be say that the ML consists of most of the fast moving vehicles whereas SL consists of slow moving vehicles.

All three highways Speed-Flow-Density diagrams are shown in the following Table. From figure 3(a) and 4(a), it is clear that the average travel speed of ML for 4 lane and 6 lane highways is higher that the SL at the same density. But it is observed that (figure

5(a) and 5 (c)) the flow rate of 8 lane highway is higher for SL than the ML. Hence the density is also high for SL than ML of the 8 lane highway. This may be due to the higher number of truck traffic in SL of 8 lane highway. Figure 3(c) shows that there is a large variation in flow range and average travel speed of 4 lane divided highway. It is observed that there exist an inverse result for the 8 lane highway i.e. figure 5(c) than the 4 lane highway i.e. figure 3(c). This variation may be due to the higher number of truck traffic in the shoulder lane of 8 lane highway. Hence it is observed that higher speed vehicles travel at ML and slow moving vehicles travel at the SL. The variation in traffic characteristics of SL and ML is clearly observed from the graphs shown in Table 2.

### 5.2 Lane specific speed and time headway distribution of all three highways

#### 5.2.1 Speed Distribution

Figures 6(a), 6(c) show the probability distribution of speed of ML and SL for NH–37. The speed distribution of ML and SL for NH-37 best fits the Gamma distribution. It also fits other distributions such as Log-Logistic, Log Normal, and Normal etc. with 1% significant level. These also indicate that, though the average speed of the ML is higher because of higher number of fast moving vehicles, but most of the fast moving vehicles have speeds more than 70 km/h (owing to two closed peaks around 70 km/h). Thus, the maximum spread of the speed distribution is on the higher side of the mean value (74.2 km/h). In case of SL, the distribution is more or less symmetric (as associated skewness of SL is less in magnitude as compared to the same in ML) which contains slow moving vehicles (40-48 km/h). Figure 7(a) and 7(c) shows the probability distribution of speed of ML and SL for NH–8.It indicates that the speed distribution of ML for NH-8 also best fits the Gamma (3P) distribution while the same for the SL. The maximum spread of the Gamma speed distribution in ML is on the higher side of the mean value (73.227 km/h). In case of SL, the distribution is more or less symmetric which contains slow moving vehicles (45-65 km/h).Similar to the 4 lane highway, the speed distribution of ML/SL also satisfies Normal, Lognormal and Log-logistic distribution for 1% significant level. It can be seen in these tables that the speed distribution in the ML has a higher kurtosis than the same for the SL. This is because the speed distribution of median lane has two closed peaks whereas the speed distribution for SL has a single peak. This indicates that the speed variation in the ML around the mean speed is higher. Figures 8(a) and 8(c) show the probability distribution of speed of ML and SL for NH–1. It is observed that, distribution follows Log-Logistic distribution for ML and SL. Since the number of slow moving vehicle is relatively small, the speed distribution tends to go towards the lower mean value speed. Thus, the skewness is negative.

Table 2 Lane Specific Speed-Flow-Density Diagrams of all three types of Highways

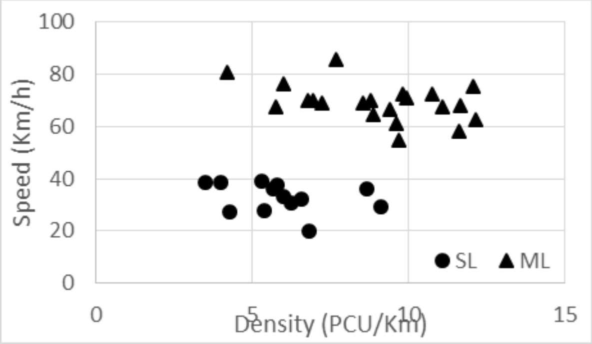
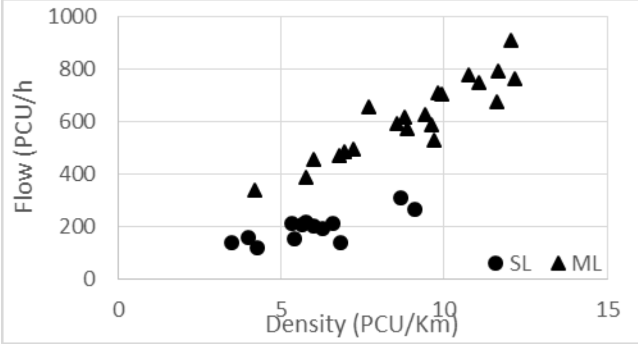
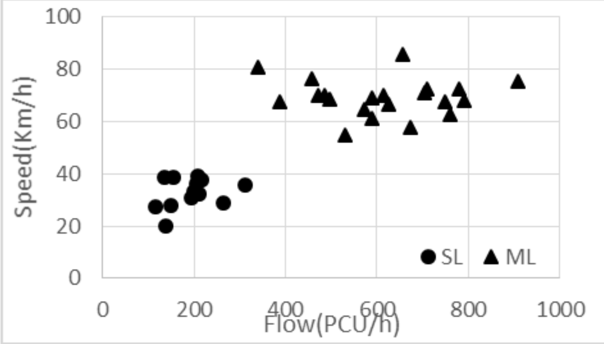
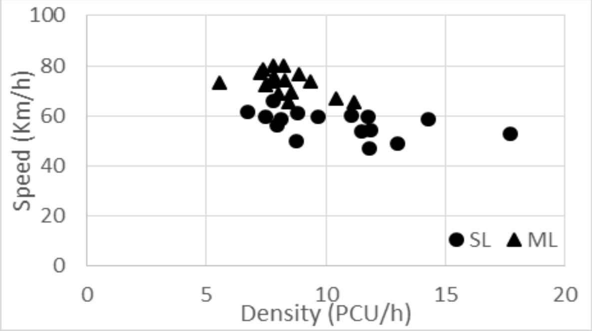
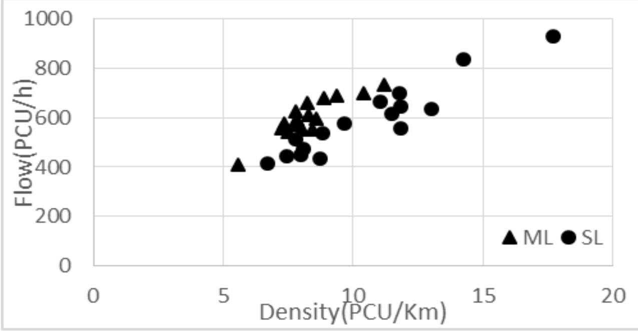
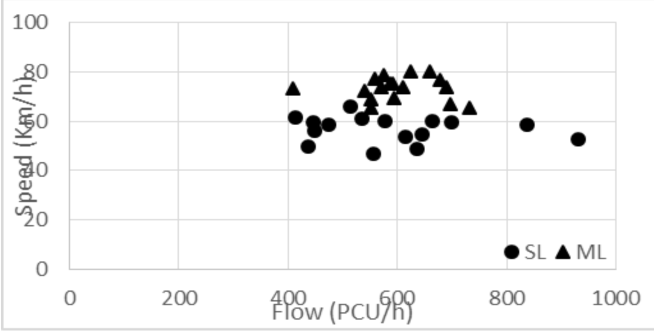
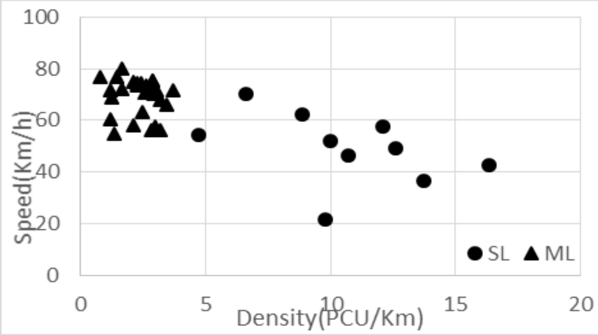
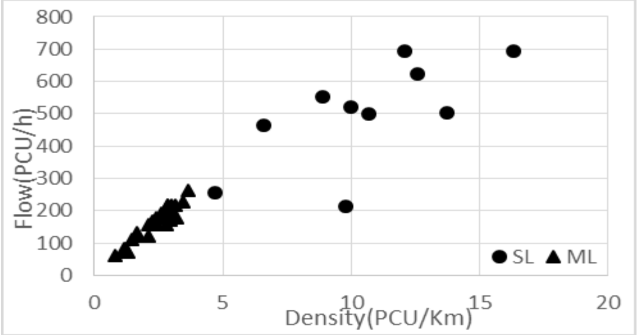
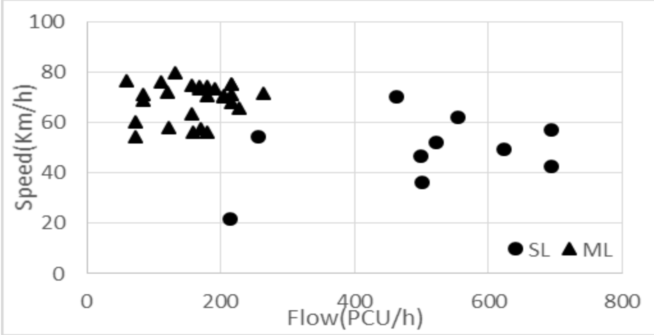
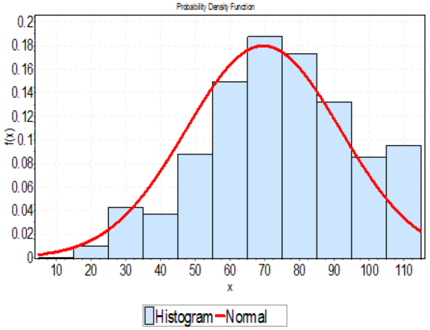
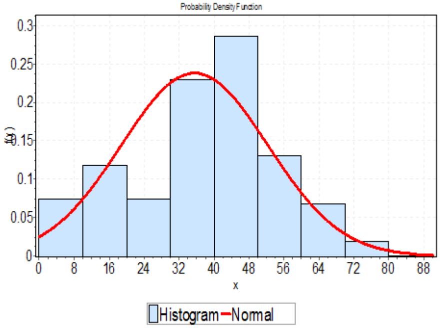
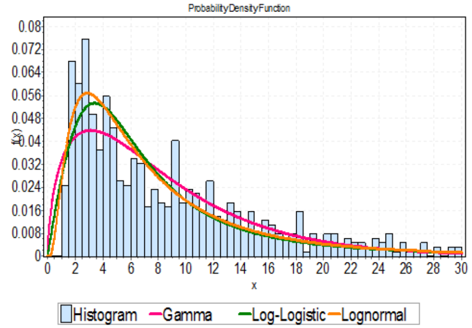
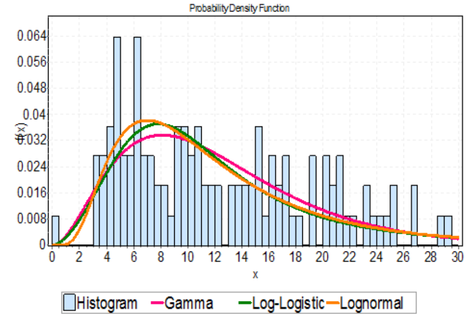
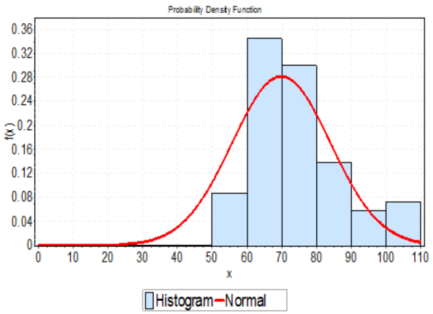
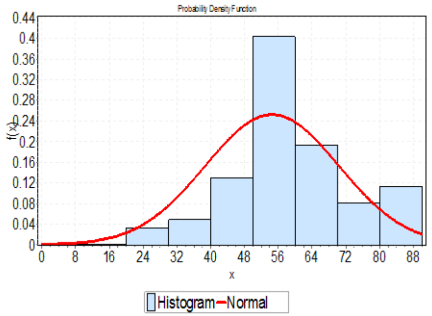
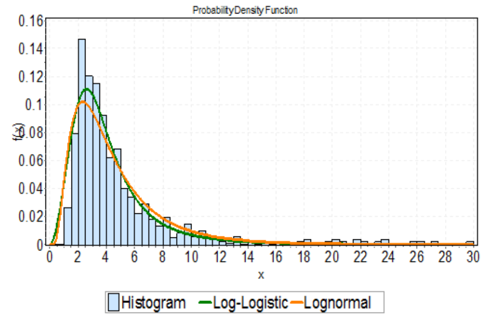
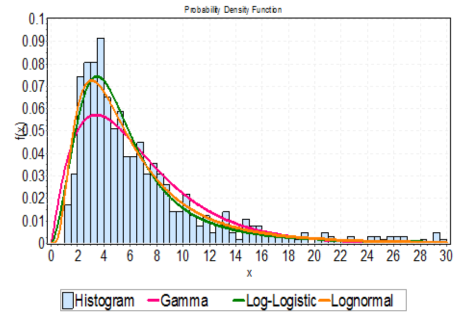
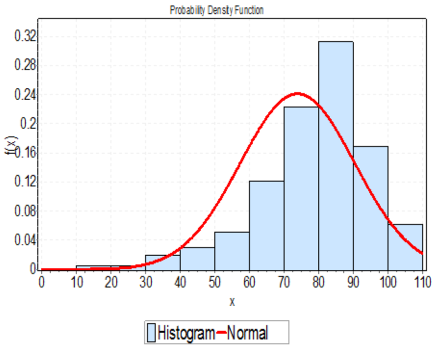
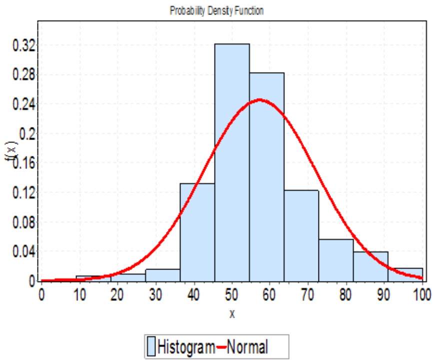
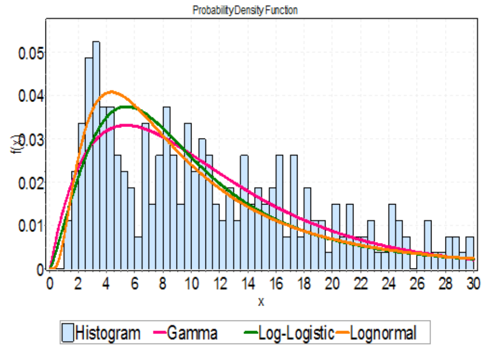
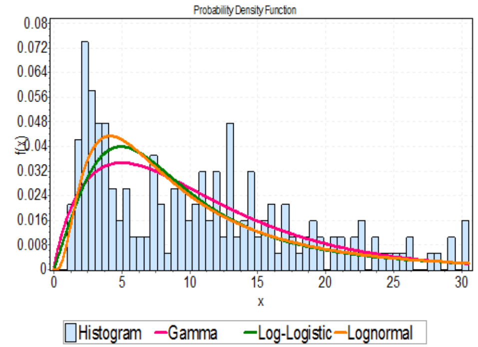
| | | | |
|---|---|---|---|
| 4 Lane Highway (NH-37) | <br>Figure 3 (a) Speed Density Diagram of ML/SL of 4 Lane Highway | <br>Figure 3(b) Flow Density Diagram of ML/SL of 4 Lane Highway | <br>Figure 3(c) Speed Flow Diagram of ML/SL of 4 Lane Highway |
| 6 Lane Highway (NH-8) | <br>Figure 4(a) Speed Density Diagram of ML/SL of 6 Lane Highway | <br>Figure 4(b) Flow Density Diagram of ML/SL of 6 Lane Highway | <br>Figure 4(C) Speed Flow Diagram of ML/SL of 6 Lane Highway |
| 8 Lane Highway (NH-1) | <br>Figure 5(a) Speed Density Diagram of ML/SL of 8 Lane Highway | <br>Figure 5(b) Flow Density Diagram of ML/SL of 8 lane Highway | <br>Figure 5(c) Speed Flow Diagram of ML/SL of 8 Lane Highway |

Table 3 Speed and Headway distribution of ML/SL for all 3 types of highways

| | Speed Distribution **(ML)** | Speed Distribution **(SL)** | Headway Distribution **(ML)** | Headway Distribution **(SL)** |
|---|---|---|---|---|
| 4 Lane Highway (NH-37) |   Figure 6(a) Speed Distribution for ML (NH-37) |   Figure 6(b) Speed Distribution for SL (Nh-37) |   Figure 6(c) Headway Distribution for ML(NH-37) |   Figure 6(d) Headway Distribution of SL (Nh-37) |
| 6 Lane Highway (NH-8) |   Figure 7(a) Speed Distribution for ML (NH-8) |   Figure 7(b) Speed Distribution for SL (NH-8) |   Figure 7(c) Headway Distribution for ML (NH-8) |   Figure 7(d) Headway Distribution for SL (NH-8) |
| 8 Lane Highway (NH-1) |   Figure 8(a) Speed Distribution for ML (NH-1) |   Figure 8(b) Speed Distribution of SL (NH-1) |   Figure 8(c) Headway Distribution for ML (NH-1) |   Figure 8(d) Headway Distribution for SL (NH-1) |

### 5.2.2 Time Headway Distribution

The Figures shown in Table 2 for headway distribution show the distribution of headway for ML and SL. 5% of the longer headways has been exempted from the distributed data for each ML and SL. It shows that the headway distribution of ML and SL for all three types of vehicles shows a wide range of variation. From figure 7(c) and 7(d) it is observed that, the variation in headway is higher for SL comparing to ML. There exists a high peak only for headway lying in the range of 2-2.5 sec in ML of 6 lane highway. Variation in headway for SL of all three types of highways is more comparing to the ML. this may be due to the variation in vehicle composition of SL from ML (maximum percentage of cars in ML). It is observed that the Log-Logistic and Lognormal distribution fits the headway of all the 3 types of highways with 1% significant level (Figure 6(c), 6(d), 7(c), 7(d), 8(c) and 8(d)). It can also be seen that the Gamma distribution also fits to the headway distribution of ML/SL of 8 lane highway and SL of 4 lane highway with 1% significant level (Figure 8(c), 8(d) and 6(d)).

### 5.3 Percentile distribution of lateral gap w.r.t. vehicular speed

The lateral position refers to the sideways position in relation to the road markings or to another predefined part of the road. Speed and lateral vehicle position are often the measures used to evaluate driver behavior changes after implementation of on-road engineering treatments, such as pavement markings and rumble strips etc. Several factors like speed, traffic composition, weather condition, lighting condition, roadway geometry design features, driver's physical condition and personal attributes may also have an influence on the lateral position of vehicles. In this section we will concentrate on speed and lateral position adaption for three different types of highways with variation in number of lanes.

The observed speeds were classified into suitable intervals generally 10 km/h to determine frequency distribution of lateral gap w.r.t. speed range. Percentile distribution is the distribution of lateral gap percentile for different speed range. The $85^{th}$, $50^{th}$ and $15^{th}$ percentile variation in lateral gap w.r.t. speed range of 10kmph has been plotted. The figure shows the variation in lateral gap w.r.t. speed.

### 5.3.1 Four Lane Divided Highway:

The percentile variation of lateral gap with respect to the increase in speed range for all the mixed vehicle type is plotted in the following figure 9(a) and 9(b) for both the median lane and shoulder lane.

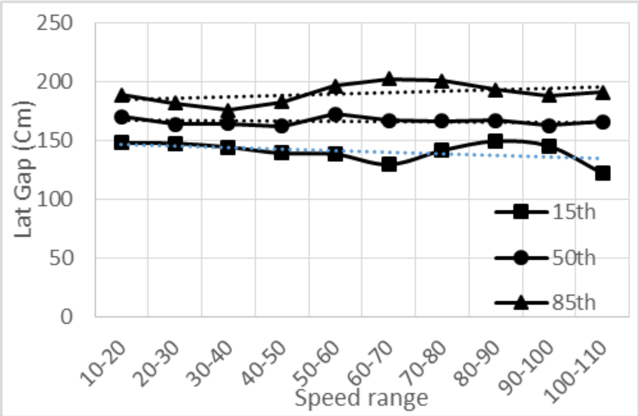



Figure 9(a) Percentile Distribution of Lateral Gap w.r.t speed range of ML (NH-37)

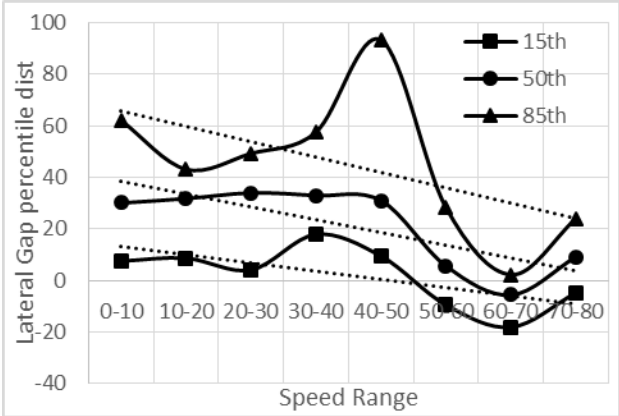



Figure 9(b) Percentile Distribution of Lateral Gap w.r.t speed range of SL (NH-37)

From the above figure it can be observed that the percentile wise lateral gap variation w.r.t the increase in speed range was constant in case of ML. It can be seen that the variation in lateral gap for median lane lies between 150 cm to 200 cm. most of the vehicles maintaining more than 100 cm gap from the road marking of Median. Whereas from figure 9(b), it can be seen that the lateral gap decreases with the increase in speed range. Hence there exist an inverse relation between the speed and lateral gap. The negative distance indicates that the vehicles are moving beyond the road marking. This may be due to the paved shoulder condition and higher percentage of 2W (50.62%) present in the SL. It is observed that the maximum lateral gap lies within 80 cm. Hence we can conclude that the vehicles maintain larger lateral gap in case of ML than SL. This may be due to the drivers perceives the median as an obstacle. Hence for the safety it maintains gap more than 100 cm from the raised median.

**Vehicle type wise percentile distribution of Lateral Gap:**

From figure 3 it is observed that there exist a variation in vehicle composition of the ML and the SL. ML contains most of the car traffic and truck traffic whereas SL contains car and 2W. A comparative study is done for the lateral gap variation of car for both ML and SL. The variation in lateral gap w.r.t speed range is also plotted for 2W and truck traffic also.

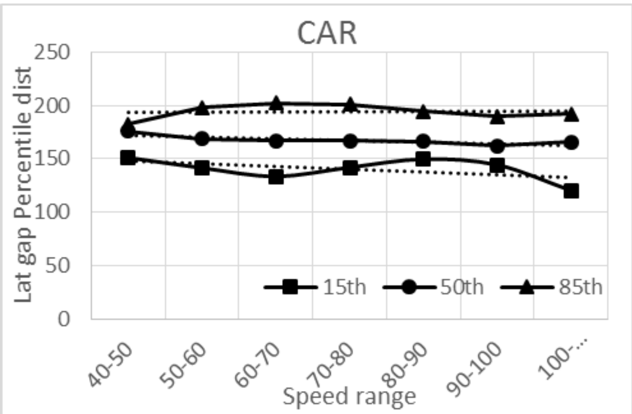



Figure 10(a) Lateral Gap percentile distribution of CAR for ML

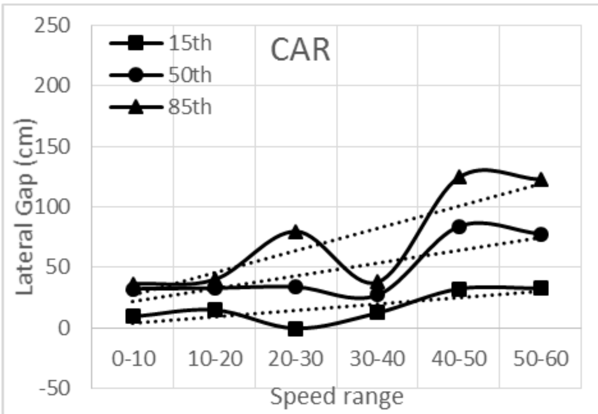



Figure 10(b) Lateral Gap percentile distribution of CAR for SL

From figure 10(a) and 10(b), it can be seen that there exists no variation in lateral gap percentile distribution w.r.t the increase in speed range. The lateral gap maintained by car lies between 100 cm to 200 cm as in case of mixed vehicle composition. But in case of shoulder lane the lateral gap increases w.r.t the increase in speed range. This result is totally opposite to the shoulder lane combined vehicle composition. This may be due to the reason that the car composition is very less i.e. only 25% of the total vehicle type whereas the composition of 2W is more than 50%.

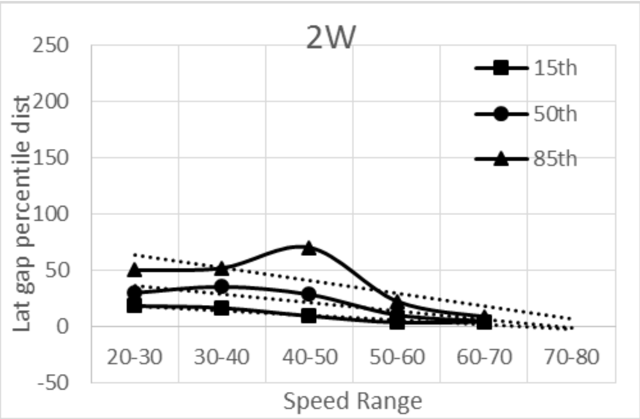



Figure 11(a) Lateral Gap percentile distribution of 2W w.r.t speed range (SL)

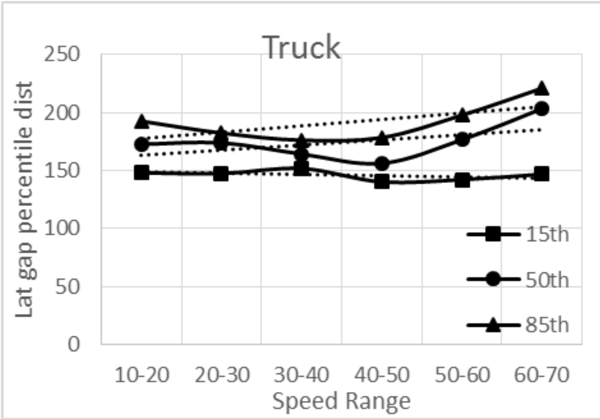



Figure 11(b) Lateral Gap percentile distribution of truck w.r.t speed range (ML)

The lateral manoeuvrability of 2W is very high in Indian road condition. The 2W moves beyond the road marking due to the paved shoulder condition. Whereas figure 11(b) shows that there exist a very less variation in lateral gap w.r.t increase in speed range.

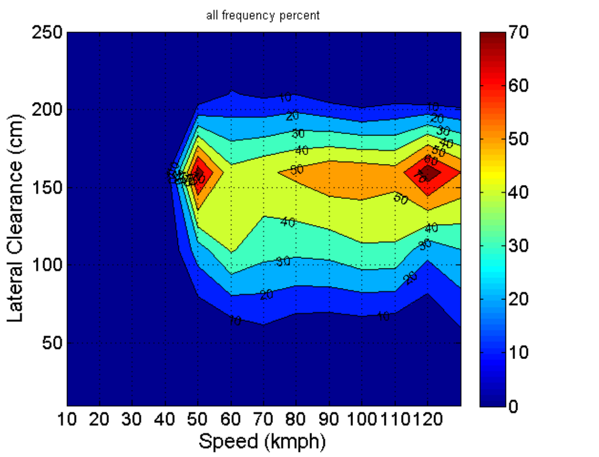



Figure 12(a) Frequency distribution of Lateral Gap w.r.t speed range for car of ML; Contour Map

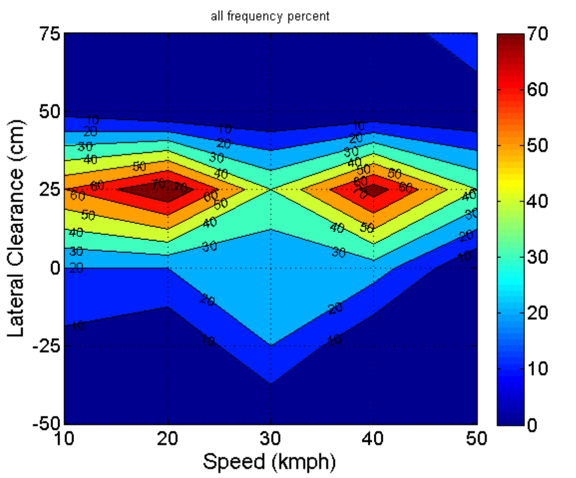



Figure 12(b) Frequency distribution of Lateral Gap w.r.t speed range for car of SL; Contour Map

Above figure 12(a) and (b) shows the contour graph of the relative frequency distribution of lateral gap with respect to the speed range. Contour line with certain value (say 40) indicates that 40% data fall within the contours. From Figure 12(a), it can be seen than the maximum number of data/vehicles follow the lateral clearance around 150cm.

### 5.3.2 Six Lane Divided highway:

The percentile variation in lateral gap of all mixed vehicle type is shown in the following figure 13(a) and 13(b) for both ML and SL.

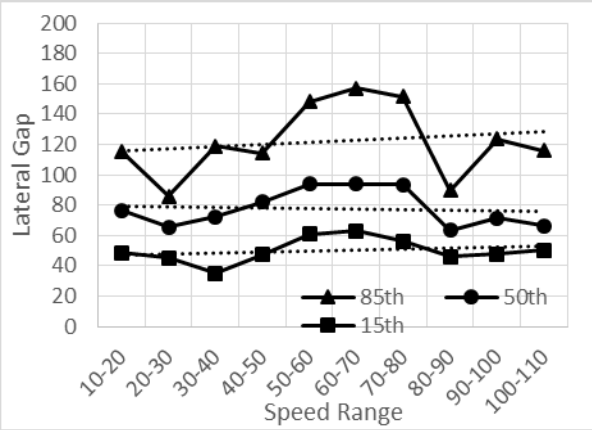



Figure 13(a) Percentile Distribution of Lateral gap w.r.t speed range for ML (NH-8)

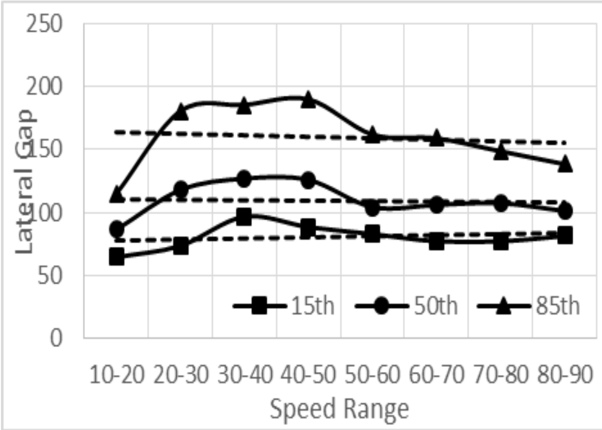



Figure 13(b) Percentile Distribution of Lateral gap w.r.t speed range for SL (NH-8)

From the above figure 13 (a), it can be observed that, up to 50$^{th}$ percentile there is no variation in lateral gap w.r.t the increase in speed range in case of ML. But for 85$^{th}$ percentile it shows a slightly increasing trend for ML. The maximum and minimum lateral gap maintained for all type of vehicles lies between 40 cm to 160 cm. This may be due to the presence of crash barrier at the edge of the road. Hence, the driver moves away from the barrier for safety with the increase in speed. Whereas from figure 13(b), it is observed that, there exists a slightly decreasing trend for the percentile variation in lateral gap for SL w.r.t increasing speed range. The maximum and minimum range of lateral variation lies between 40 cm to 200 cm for SL. The lower range of lateral gap for ML as well as SL is same. This may be due to the presence of paved shoulder and crash barrier in both the edges of the road. Hence vehicles maintain similar gap in both ML and SL. The higher range of lateral gap varies in both cases. The maximum lateral gap is 200 cm for SL, this may be due to the presence of both slow and fast moving vehicles in SL. As it is a 6 lane divided highway, each side contain 3 lanes. Hence in case of SL as the speed increases the vehicles shifts towards the middle lane. The decreasing trend of SL may be due to the presence of very high percentage of 2W (i.e. 60%).

**Vehicle Type wise percentile Distribution of Lateral Gap:**

From Table 1 it has been seen that, the ML for 6 lane divided highway consists of most of the car traffic (96%) whereas the SL contains most of the 2W (60%), Car (17%) and Truck traffic (16.6%). Hence a comparative study can be made for the lateral gap variation of car traffic of ML and SL. The following figure shows the percentile variation in lateral gap of car for both ML and SL.

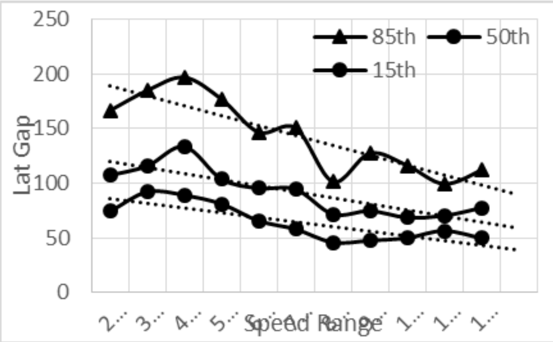



Figure 14(a) Percentile Speed distribution of Car w.r.t speed range for ML (NH-8)

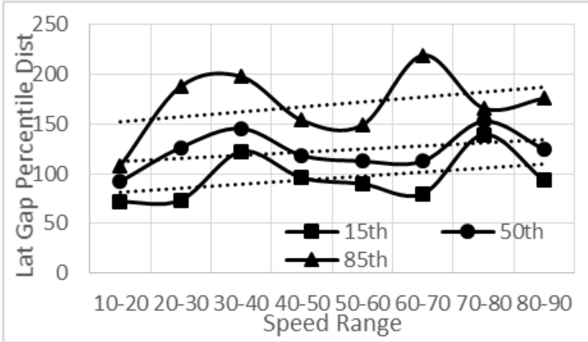



Figure 14(b) Percentile Speed distribution of Car w.r.t speed range for SL (NH-8)

From the above figure 14(a), it has been seen that the lateral gap decreases with the increase in the speed range in case of ML. The ML is the outer lane of the 3 lane road. Hence all the fast moving vehicles moves towards the outer lane (ML). This may be due to the presence of crash barrier at the side of the road. Hence the vehicles feel free to drive closer to the barrier. As shown in figure 14(b), the lateral gap increases with the increase in the speed range. This may be due to the shift of the vehicles from inner lane (SL) to the outer lane i.e. the middle lane and then the median lane. For both the ML and the SL the lateral gap variation lies between 50 cm to 200 cm. this may be due to the same barrier condition (crash barrier), for both the ML as well as SL.

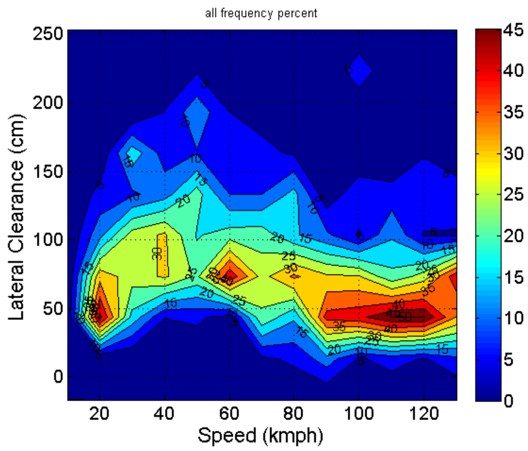



Figure 15(a) Frequency distribution of Lateral Gap w.r.t speed range of ML; Contour Map

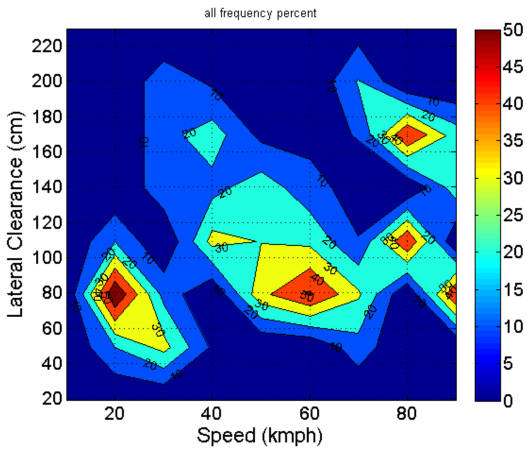



Figure 15(b) Frequency distribution of Lateral Gap w.r.t speed range of SL; Contour Map

### 5.3.3 Eight Lane Divided Highway

The percentile variation of lateral gap w.r.t speed range is shown in the following figure 16(a) and 16(b).

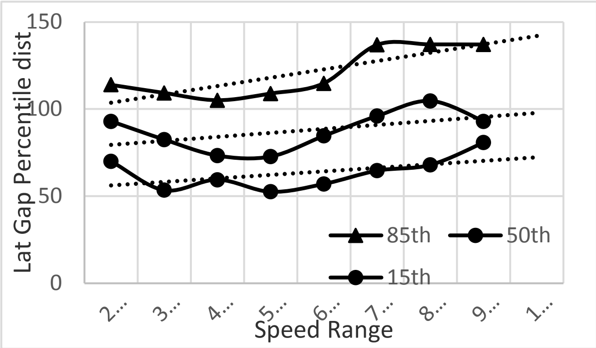



Figure 16(a) Percentile Lateral Gap variation w.r.t speed range of ML (NH-1)

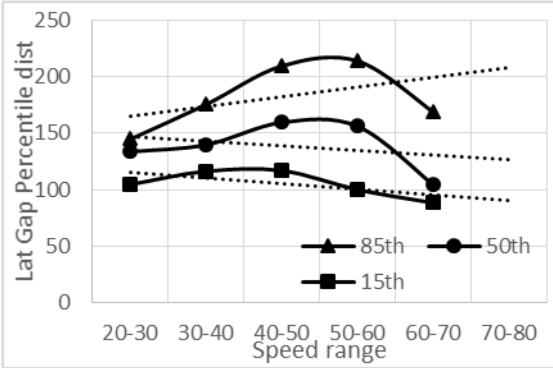



Figure 16(b) Percentile lateral Gap variation w.r.t speed range of SL (NH-1)

From the above figure it is observed that, up to 50$^{th}$ percentile the variation in lateral gap w.r.t the speed range is almost constant for ML and SL. The 85$^{th}$ percentile lateral gap variation shows an increasing trend w.r.t the increase in speed. The increasing trend shows that as the speed of the vehicles increases, they maintain a larger distance from the road edge for safe driving condition to avoid the crash. The variation in lateral gap lies within 50 cm to 150 cm for ML whereas 100 cm to 250 cm for SL. It shows that the vehicles of SL maintains higher gap than the ML. This may be due to the variation in the edge condition. The ML contains fencing barricade at 50 cm distance away from the kerb, i.e. 85 cm away from the road edge, whereas the SL contains crash barrier with raised kerb which is only 15 cm away from the road edge. Hence due to the larger distance of the fencing from the road edge, the vehicles travel closer to the road edge than the SL. As the crash barrier along with raised kerb, lies only 30 cm away from the road edge, the drivers perceives the barricade as an obstacle. Hence for safety reason, vehicles maintain a larger distance from the edge lane in SL.

**Vehicle Type wise percentile distribution of Lateral Gap:**

From Table 1 it can be see that the vehicle composition of ML and SL of the 8 lane divided highway is totally different. The ML contains most of the car (98.98%) traffic and only a very few percentage of Bus (1.12%) traffic. Whereas the SL contains most of the truck (44.23%) and two wheeler (49.36%) only and a very small percentage of car (1.92%), three wheeler (2.99%), and bus (1.45%) traffic. As the variation in the traffic composition is very high, no comparative study can be done between the ML and SL traffic. Hence the lateral gap percentile variation for ML and SL w.r.t the speed range is shown in the following figure.

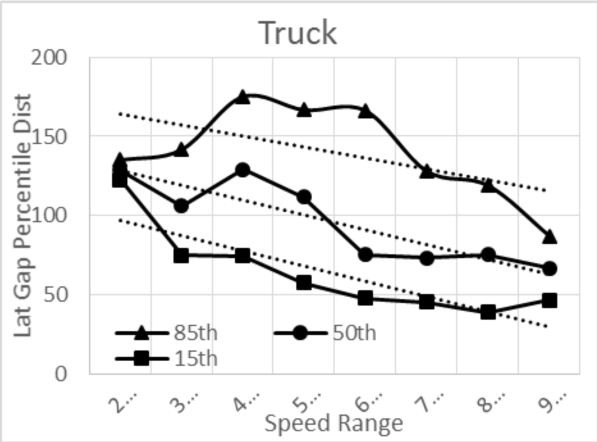



Figure 17(a) Percentile Distribution of Lateral Gap w.r.t speed range for Truck (SL)

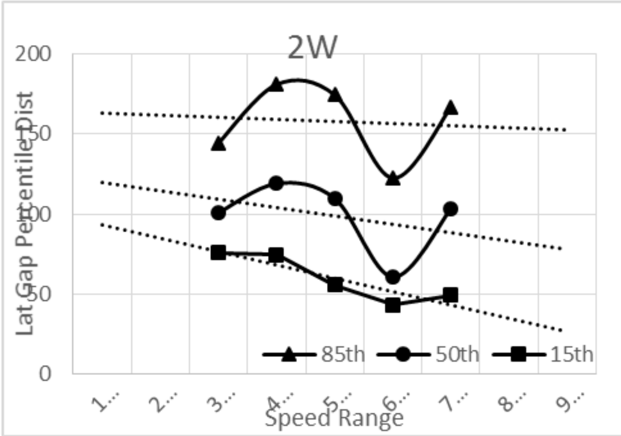



Figure 17(b) Percentile Distribution of Lateral Gap w.r.t speed for 2W (SL)

The SL contains most of the Truck and 2W traffic. The variation in lateral gap w.r.t speed shows a decreasing trend for truck and an increasing trend for 2W. This may be due to the static characteristics of the vehicle. As the truck has a very less lateral movement then the 2W. 2W generally tries to overtake the front vehicle with the increase in speed. Hence It shows an Increasing trend w.r.t speed range. It has been observed that, trucks are travelling at the outer lane of the 4 lane road. Due to the mixed traffic condition of highway, trucks avoid the overtaking operation while they are travelling with the other slow moving vehicles due to the larger size. The decreasing trend observed is may be due to the type of crash barrier present in the shoulder. It can be seen that the trucks maintain maximum 200 cm and minimum 50 cm distance from the road edge, while two wheeler maintain more or less the same. But from Figure 17(a) and 17(b), it is clear that the variation in lateral gap is higher for two wheeler than the truck. This may be due to the static as well as the dynamic characteristics of the vehicles.

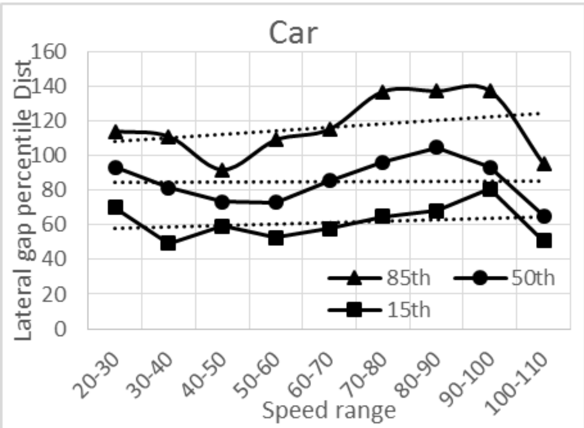



Figure 18(a) Percentile variation in Lateral Gap of Car w.r.t the speed for ML

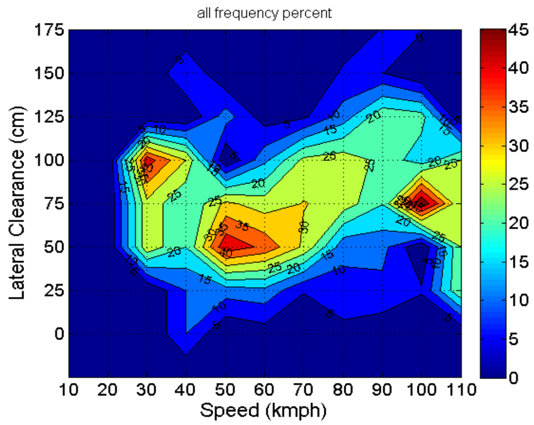



Figure 18(b) Frequency distribution of Lateral Gap w.r.t speed range for car of ML; Contour Map

It has been observed that 98.89% of Car is present in ML. Hence we can conclude that the high speed vehicles travel at the inner most lane of the 4 lane road. The figure 18(a) shows an increasing trend for Car. As, ML is the inner most lane of the road, there is no space at the right side of the lane. Hence, vehicles wants to overtake the front vehicle also moves to the inner lane and overtakes. Hence, it is observed that, vehicles maintain higher distance with the increasing speed range. This may be due to the safety perception of the driver, to avoid the crash of the vehicle. Cars maintain 40 cm to 140 cm distance from the road edge at the ML. The variation in the lateral gap is also less compared to the SL vehicles.

## 6. CONCLUSION

In the present study, the impact of different lane positions, i.e. the ML and SL has been analyzed for 4 lanes, 6 lanes and 8 lanes divided highways in India on average travel speed. A sensor assembly has been developed which consists of two ultrasonic sensors placed alongside the road at a known distance with a camera. It measures (i) Lateral clearance maintained by vehicles from road elements (ii) Vehicle's speed traveling near edge lane (ML/SL). Operation of this assembly is semi-automatic with little intervention. Speed, flow and vehicle composition of ML & SL of all highways have been calculated from the field data.

Lane specific average speed, time headway and lateral gap for each vehicle type on different roads are computed. Individual lane wise statistical analysis has been done for the 4 lanes, 6 lanes and 8 lanes divided highway. Comparative vehicle type wise analysis has been done for the 4 lane and the 6 lane highway. The comparative lane specific vehicle type wise analysis is not possible in case of 8 lane highway because of the wide variation in vehicle composition of the ML/SL.

- The analysis shows the significant speed variation between the lanes of each highway.
- It is observed that, fast moving vehicles generally tend to move in the ML than in the SL.
- Hence, the variation in mean speed between ML and SL decreases with the increase in the number of lanes of the highways.
- It has also been observed that cars constitute the maximum traffic composition in ML i.e. 70-99% for all three type of highways. Whereas two wheelers in general constitute the maximum traffic composition in shoulder lane.
- Because of the heterogeneous or mixed traffic composition in India, there exists a wide variation in the lane specific speed distribution patterns for all the three types of highways.
- It is observed that, the variation in time headway is higher for SL comparing to ML.
- This may be due to the variation in vehicle composition of SL from ML (maximum percentage of cars in ML).
- The variation in lateral gap for all mixed vehicle type of ML is more or less constant for all the three types of highways. This may be due to the presence of most of the fast moving vehicle in ML. So at higher speed the lateral movement of vehicles is less.
- The variation in lateral gap in SL shows an increasing trend for the six lane and 8 lane highway. Whereas it shows a decreasing trend in case of 4 lane highway. This is due to the presence of paved shoulder at the 4 lane highway whereas 6 lane and 8 lane highway has crash barriers at the shoulder side.
- The decreasing trend of SL is due to the presence of more than 50% of two wheeler (2W).
- For 6 lane highway, the variation in lateral gap is more or less constant for ML and SL.
- The decreasing trend of car for ML of 6 lane highway is may be due to the presence of crash barrier at the median side. Hence vehicles feel safe to drive closer to the barrier.

- The variation in lateral gap of two wheeler (2W) and truck of SL shows a decreasing trend with the increase in speed whereas the car of ML shows more or less constant variation in lateral gap.
- 70% of the lateral gap of all three highways varies with in 50 cm to 150 cm distance from the road edge. whereas two wheelers (2W) maintain 50 to 100 cm lateral gap from the road edge.

The results obtained here validate the finding of the background study. It can be concluded that the there exists a wide variation in the lane specific vehicular speed, traffic composition, time headway and lateral gap etc. in the Indian heterogeneous and mixed traffic condition of Indian highways. The variation in lateral gap may also depends on various other road features except speed and the number of lanes. Hence a detailed study in the lane specific traffic characteristics is required for the Indian highways, which affect the average travel speed of the road, capacity and the road safety.

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