Jurnal
Teknologi

Full Paper

LATERAL MOVEMENT OF VEHICLES UNDER WEAK-LANE DISCIPLINE HETEROGENEOUS TRAFFIC

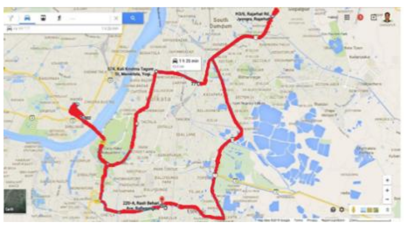
Geetimukta Mahapatra[a], Akhilesh Kumar Maurya[a], Anil Minhans[b*]

[a]Department of Civil Engineering, Indian Institute of Technology Guwahati, Assam, India 781039
[c]Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Article history
Received
30th April 2015
Received in revised form
2nd August 2015
Accepted
1st October 2015

*Corresponding author
anilminhans@utm.my

Graphical abstract



Abstract

Safe driving can be achieved by prevention of risky situations which requires the knowledge of the vehicle dynamics and road geometry. The Indian traffic condition is heterogeneous in nature and has weak lane discipline. Hence, vehicles interactions takes place laterally also along with their longitudinal interaction. Vehicles lateral movements (interactions) are quite high due to absence of lane discipline. Therefore, the lateral acceleration of vehicles are an important variable which characterizes the corresponding vehicle dynamics. Several studies have been done by various authors on lateral acceleration in curves, however, lateral movement study of vehicles on straight road section is also important to analyze vehicles' maneuver in such traffic (i.e. traffic stream with weak lane discipline). Therefore, the present study is about the observation of lateral movements of vehicles over different types of roads in three metropolitan cities of India (Kolkata, Mumbai and Pune) under moderate traffic conditions. Lateral acceleration variation of five different types of vehicles (SUV cars, Sedan cars, Hutch Back cars, motorized three wheeler and two wheeler) have been recorded to investigate its relationship with vehicles longitudinal characteristics (i.e. longitudinal speed) in Indian heterogeneous and weak lane disciplined traffic. Lateral acceleration values quickly rises with initial increase in speed afterward lateral acceleration values reduces with further increase in vehicles longitudinal speed. Impact of vehicle type and locations on the lateral maneuvering of vehicles have also been studied

Keywords: No lane discipline; heterogeneous traffic; mixed traffic; vehicle type; lateral acceleration; vehicle maneuvering.

1.0 INTRODUCTION

The view of the long unending Indian traffic from an elevation is a sight with an enormous pressure of a few hundreds and thousands of vehicles ramping on the roads every day. This sight is mesmerizing with various types of vehicles such as the buses, cars, two wheelers, and auto-rickshaws plying on the roads, packed side to side, claiming their spaces on the roads and moving on inactively. There are no strict lanes of traffic, just one immensely colossal mass and without any proper discipline. Lanes are defined by broken or solid white lines which are not even maintained properly. Lane discipline definition in terms of driving is when a driver abides by the regulation that he/ she should always keep his/ her vehicle strictly within the road markings which indicate the lane, unless a lane change or direction is necessary. However, such lane behaviour is a fancy in Indian traffic conditions and is generally not seen. In fact, Indian traffic condition is heterogeneous in nature with no strict lane discipline.

The task of driving can be defined as tracking a path or a lane along a given roadway. An important skill in driving is the perception of the lateral force (apart from the longitudinal forces from its leading vehicle) which results from a change in the direction of motion of the vehicles. The consequentiality of these lateral forces increases in case of non-lane disciplined roads. Vehicle in such streams continuously interact with the vehicles which are present in its neighbourhood (longitudinal as well as lateral directions). This forces a change in the vehicle longitudinal as well as lateral position on road to optimise its speed and travel time. Lateral behaviour of vehicles are influenced by several factors such as road geometry, traffic behaviour and space availability between vehicles. Hence on a given road section, the lateral positioning depends upon the behaviour of the driver, the type of the vehicle and most importantly, the traffic parameters such as the vehicle speed and it's acceleration.

The longitudinal interaction of the vehicles in traffic stream has been studied for quite a long time. However, the lateral behaviour of the vehicles (one of the most important criterion for the Indian traffic conditions) has not been explored much until now. Due to the no lane discipline and mixed traffic conditions, the lateral movement of vehicles is significantly high as compared to other countries where drivers follow proper lane discipline. Hence, the driver not only interacts longitudinally with the vehicles ahead but also laterally with the vehicles along its sides. The choice of the vehicle's speed will thus also depend on the lateral acceleration of the vehicle and the vehicles nearby (both ahead as well as alongside). Hence, such studies are important for the realistic traffic flow modelling incorporating the effect of various traffic features like vehicles ahead, vehicles to the side, the heterogeneous and mixed traffic condition, etc. along with the driver behaviour.

Further, the results of lateral movement studies of different vehicles helps in establishing the thresholds/safe lateral acceleration values for different vehicle types in different traffic scenarios. These threshold values can be used to identify the reckless drivers in a traffic stream in order to improve the traffic safety.

In the past, some work has already been done to know the vehicles' lateral movement behaviour. These studies have been conducted in different countries to explore the change in the behaviour of vehicles lateral position with respect to the different traffic parameters (Speed and vehicle type), driver behaviour, and road features (road marking, rumble strips, etc.), day or night time driving [1-4]. It has been observed that there exists an endogenous relationship between the speed and the lateral vehicle position [5-6]. However, most of the studies have been conducted on curved roads. To the best of the authors' knowledge, studies related to the behaviour of vehicles lateral position in no (or weak) lane disciplined traffic has not been found. Such heterogeneous and weak lane disciplined traffic consists unique characteristic of traffic composition, roadway geometry, manoeuvrability and vehicular interactions in terms of driver behaviour due to size, speed and vehicle width [5]. Therefore, studies on vehicle’s lateral movement on straight roads in Indian traffic streams needs to be conducted to analyse the weaving motion of vehicles in such traffic.

The present study focuses on the analysis of the lateral and longitudinal behaviour of vehicles in mixed traffic condition on Indian highway. This study includes the observations on the lateral behaviour of different vehicle types (SUV cars, Sedan cars, Hatchback cars, motorized three wheeler (3W) and two wheeler (2W)) and the effect of longitudinal speed on lateral behaviour (i.e. lateral acceleration) of vehicle on different types of roads of three metropolitan cities of India in moderate traffic conditions.

2.0 LITERATURE REVIEW

It is essential to know the vehicle’s lateral characteristics, i.e. the vehicle’s lateral position and the corresponding lateral speed in mixed traffic conditions with no proper lane discipline. This paper mainly focuses on the resoluteness of the vehicle’s lateral acceleration at different longitudinal characteristics.

The factors effecting the variability of lateral position and its importance have been studied by various authors. Sarosh and Pawan [5] gave a comprehensive review of the few studies on mixed non-lane based traffic in Indian, Bangladesh and Indonesia. There exists a unique characteristic of traffic composition, roadway geometry, manoeuvrability and vehicular interactions in terms of driver behaviour. Due to size, speed and vehicle width, a unique decision making process is necessary for overtaking and passing. The sheer width of the road way often determines the range of driver behaviour and thus, the interaction among vehicles. Hence, there exists higher lateral manoeuvrability in the above mentioned developed countries. Reymand and Kemeny [7] concluded that the drivers adjust their speed in curves so that the maximum vehicle lateral acceleration decreases at higher speeds. It was anticipated that extreme values of lateral acceleration in curves decrease and this diminution is quadratic in nature with respect to the speed in accordance with the experimental data obtained from a vehicle driven on test track and a motion based driving simulator. Again according to Lennie and Bunker [8], with the worsened level of service, headways become smaller and thus drivers appear to compensate by increasing their lateral separation/ position. As traffic condition become heavier, the lateral position of all vehicles became more precise as noticed by the smaller standard deviations in lateral position. Again, Rosey and Auberlet [9] studied the trajectory variability using driving simulator. The analysis of the variability of vehicle trajectories reveals how situational constraints influence drivers’ behaviour (e.g. lateral position or speed). They assessed the variability of the lane position as a simple indicator of road geometry. Lewis and Samuel [10] studied the explicit and implicit process in behavioural adaption to road width using a driving simulator. The wide road produced an average lane position closer to the left road edge (0.26 m from the centre of the lane) while the narrow road produced a shift away from road edge (0.37 m to the right of the lane centre). However, according to Stodart and Donell [11], the restrictive nature of roadway geometry does not produce significant variation in vehicle lane position among the vehicles. Also, two variables (i.e. curve direction and horizontal curve radius) were found to have the largest association with the change in vehicle lane position. Antonson et al. [12] stated that the surrounding landscape affects the driving behaviour. According to Santel [6], the range of lateral movement depends on several criteria like vehicle speed, vehicle type, carriageway width, vehicle status (individual vehicle / vehicle group), etc. Further, Dijksterhuis et al. [13] studied the effect of steering demand on lane keeping behaviour. Driving simulator was utilized to ascertain the changes in mental effort in response to manipulation of steering demand. Steering demand was increased resulting to narrow lane widths and high-density oncoming traffic while speed was fixed in all conditions to prevent a compensatory reaction.

Among the various studies, it had been found that vehicular speed is one of the major factors affecting the lateral characteristics of traffic. Ritchie et al. [14] conducted a study on the relationship between the longitudinal velocity and the lateral acceleration in curves during normal driving. The results showed that the lateral acceleration was an inverse function of the speed in curves. The lateral acceleration was not related to either sex or driving speed for speed range less than 20 mph. For speeds more than 20mph there exists an inverse relation for all groups. Again Felipe and Navin [1], conducted a study on the automobile movement characteristics on horizontal curves. The results indicate that for a comfortable ride, drivers are limited by their comfortable lateral acceleration (approximately between 0.35 and 0.4 g) on small radius curves and seek the environmental speed (i.e. a speed subject would travel on a straight section of the same environment) on large radius curves. Odhams and Cole [15], have also done a study which reviews the existing published models of speed choice, and compares the models by fitting them to experimental data gathered in a driving simulator experiment. The results show a clear drop-off in the lateral acceleration with the increase in the longitudinal speed. Halmark [2], performed a study by using Z configuration pneumatic road tubes on the curve road section to find if any endogenous relationship exists between the speed and the lateral positions of the vehicles. Results statistically signify that vehicles at higher speeds had greater odds of near lane crossings. We (Mahapatra and Maurya) in 2003 [16] made an initial study on the vehicles lateral movement in non-lane disciplined traffic stream on a straight road in India. The relation between the lateral acceleration and heading angle with longitudinal speed is explored for three different vehicle types (SUV cars, Sedan cars and Motorized three wheeler). There exists an inverse relationship between lateral acceleration and longitudinal speed for vehicles travelling at speed higher that 5m/s.

Several methods exist in the literature to find the lateral characteristics of the vehicles. This section gives a brief introduction to such methods. Hadri et al. [3] conducted a study on the vehicle/ road interaction and tyre lateral performance identification. They presented a new procedure for the identification of lateral tyre performance based on vehicle dynamic simulation, measurements and optimization. Brackstone et al. [4] conducted a study on the dynamic behavioural data collection using instrumented vehicle. Again a complete prototype system for measuring lateral position has been developed by Elisabeth [17]. The use of computer vision to measure lateral position can be divided into road marking detection and lateral position extraction. The best characteristics of a road marking image are the road marking edges. The road marking detection step is based on the edge detection. Yang [18] has used an image based technique to determine the vehicle heading angle. This technique uses an in-vehicle camera. The heading angle is determined by converting the front view images to their corresponding top view images via homography. This is followed by the use of the feature selection and tracking from those top view images via the Lucas-Kanade optical flow technique to determine the heading angle and the lateral displacement of a vehicle. It was observed that at 50 mph, the vehicle deviates from the centre of the lane within ±4 ft, however, at higher speed of 65mph, the vehicle deviation is within ±5 mph. Overall, the range of the heading angle lies between 18.7° to -12.76° and the lateral displacement is from 2.97 ft (right) to -2.11 ft left.

The review of the literature on lateral characteristics of vehicles reveal that the change in lateral position depends on various traffic parameters, road geometry and driver behaviour, vehicle size, traffic condition of road and surrounding landscape etc. Numerous studies have 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. Works associated 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 accurate simulation model. Therefore, present study analyses the lateral and longitudinal characteristics of vehicles in such traffic condition.

3.0 METHODOLOGY

This study explores the association of the lateral characteristics such as the lateral acceleration of different vehicles on various straight sections of three metropolitan cities of India - Kolkata, Mumbai and Pune. The setup for this study is similar to the setup discussed by our previous study on Mahapatra and Maurya [14]. The details of the setup are as follows.

For this study, V-Box, Inertial Measurement Unit (IMU) and multifunctional display along with a laptop (for real time monitoring) and battery (for power supply) are installed in the subjected vehicle. V-Box is a highly accurate GPS device which yields the vehicle position (with sub meter accuracy) and speed (with 0.0278 m/s accuracy) at 10 Hz data logging frequency. IMU is a solid-state sensor that presents the user with the measurements of angular attitude, angular rate, Earth's magnetic field, together with linear acceleration, in three orthogonal axes. A unique feature is the two sets of the acceleration measurements. One set gives sensor acceleration with respect to the sensor mounting face while the other set resolves the motion into horizontal and vertical components, regardless of the sensor point of view. This enables longitudinal and lateral acceleration measurements that are essentially free of the influence of the earth's gravity. IMU sensor is fixed tightly inside the subject vehicle at a level surface. The multi-functional display shows the various parameters measured by the V-Box and the IMU real time sensor. Such a setup is shown in Figure 1. Five different vehicle types (like hatchback car, sedan car, SUV car, motorized three wheeler and two wheeler) are considered in this study.

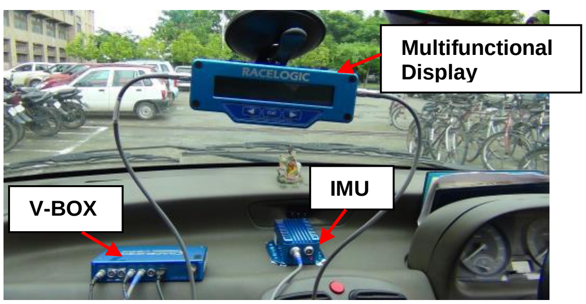
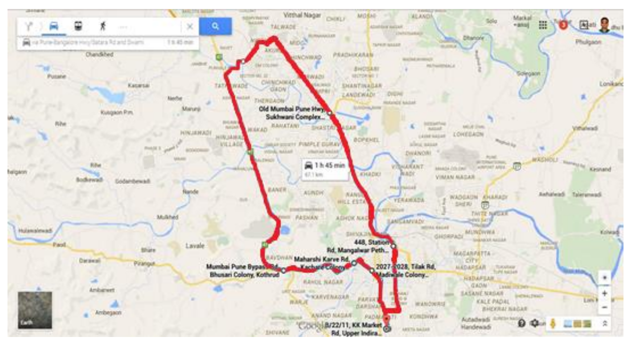


Figure 1 V-Box, IMU and Multifunction Display installed in a car

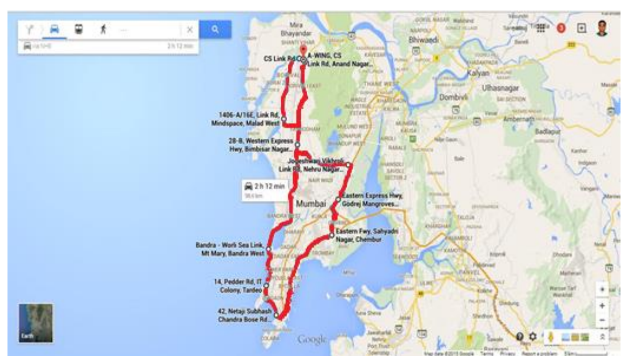
The data was collected in three different metropolitan cities (Kolkata, Mumbai and Pune). The subject vehicle was drove on the marked path (red color on the map) of the each city. Data have been collected from different types of road way facilities of different cities on December, 2014 (Dated from 1st to 20th December) during morning hours (9 am to 12 pm i.e. 4 hours) in sunny weather conditions. The experiment was conducted during moderate flow conditions to ensure the vehicle to vehicle interaction. The road surface was in good condition and proper visible lane markings were present. This section was free from any side interference. The map of all three cities where data had been collected is shown below in Figure 2.

The data corresponding to all sections were extracted in the report generator (refer Figure 3) using V-Box Tools Software. Only the straight sections have been considered for data extraction process. The length of straight portions for each city are 25000 m for Kolkata, 15000 m for Mumbai and 25000 m for Pune. This software enables configuring the setup of V-Box or to view and process the V-Box data either in real time or in post-processing. Extracted data contains various parameters like run number, speed, time, distance travelled, longitudinal acceleration, lateral acceleration, yaw rate, pitch rate, etc. corresponding to each trip. These data were analyzed for longitudinal and lateral characteristics of different class of vehicles. The results thus obtained have been discussed in the next section.

(a)



(b)



(c)

Figure 2 Maps showing the three sections of (a) Kolkata, (b) Mumbai and (c) Pune (The Red line in the map indicates the marked section)

A screen shot of the data extraction process using VBOX Tool software is shown in Figure 3.

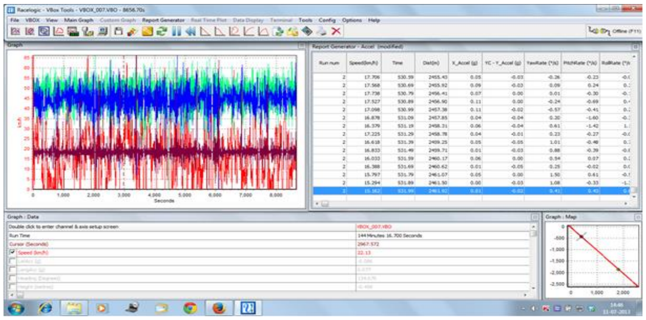


Figure 3 Screen shot of data extraction process using VBOX Tool Software

4.0 RESULT AND ANALYSIS

From the analysis of the various collected parameters, it has been observed that the variation of the lateral acceleration with the longitudinal speed needs to be explored. Therefore in the present study, the variation of the lateral acceleration with the longitudinal speed of different vehicle types for all the different three metropolitan cities has been analyzed.

Analysis of Variance (ANOVA) test has been conducted to know the significance difference between the lateral behavior with respect to the vehicle type as well as the different city. The effect of number of lanes and the effect of two different regions on the lateral maneuvering is studied.

4.1 Vehicle Type Wise Lateral Acceleration Variation In All Three Cities

Lateral acceleration is an important lateral characteristic of a vehicle which decides the weaving rate of the vehicle. The data pertaining to the lateral acceleration at different longitudinal speeds during all trips of a vehicle has been sorted. In order to see the average behaviour, lateral acceleration values are averaged over each 0.5 m/s longitudinal speed range and plotted against the longitudinal speed. The results for Kolkata for all five types of vehicles are given in Figure 4.

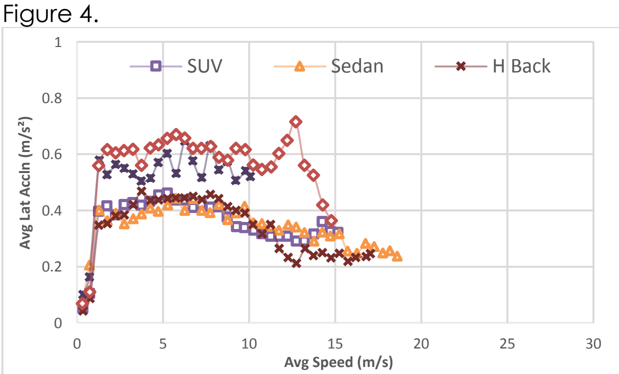


Figure 4 Relationship between lateral acceleration with longitudinal speed of vehicles in KOLKATA for all 5 types of vehicle

From Figure 4, it can be observed that there exists an idealized relationship between the lateral acceleration and the longitudinal speed for all vehicle types. It is also observed that for all class of vehicles, lateral acceleration values are low at near zero speed and it quickly increases with the increase in speed. Further, a maximum lateral acceleration value is attained with the increase in the speed. The Hatchback, Sedan and SUV, all three types of cars have more or less same type of lateral behavior. The lateral acceleration lies within 0.4 m/s², whereas the two wheeler and motorized three wheeler have high lateral acceleration than the cars, i.e. up to 0.7 m/s². Lateral acceleration values remains low (as compared to the maximum lateral acceleration values) at speed greater than 10m/s. This states that the lateral maneuverability is generally high at lower speed and reduces at higher speed. This behavior is due to the fact that the driver does not feel safe for high lateral weaving at higher speed. It is also observed that two wheeler shows the highest lateral acceleration than the other vehicles. It can be concluded that the lateral maneuverability increases with the decrease in the size of the vehicles.

Analysis of variance (ANOVA) test is conducted to see the significance of all five type of vehicles. It is observed that P_{value} is less than 0.05, where P_{value} indicates the estimated probability for rejecting or accepting the null hypothesis It is also observed that $F_{statistics} > F_{critical}$, where $F_{statistics}$ describes the statistically expected level of heterozygosis in a population and $F_{critical}$ value is the number that the test statistics must exceed to reject the test. Hence, the lateral acceleration for all five types of vehicles is significantly different at 5% significance level. The null hypothesis is rejected. By the standard error test it is observed that the standard difference between the mean values for all three types of cars (H-Back, Sedan and SUV) is higher than the standard error. Hence mean of lateral acceleration of all the cars are strongly different from the mean of two wheeler and motorized three wheeler.

Likewise, the plot of the lateral acceleration versus the longitudinal speed for Mumbai has been shown in Figure 5.

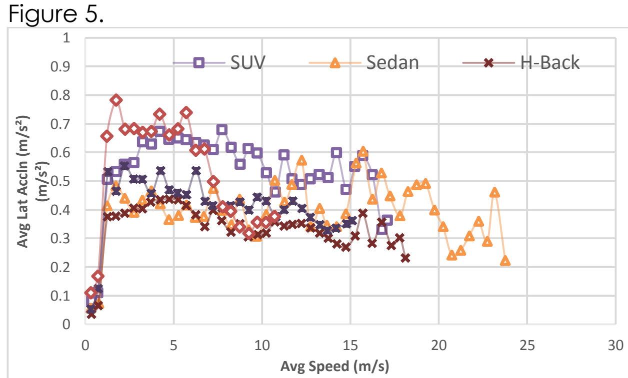


Figure 5 Relationship between lateral acceleration with longitudinal speed of MUMBAI for all 5 types of vehicle

From Figure 5, it can be observed that, for all class of vehicles, lateral acceleration values are low at near zero speed and it quickly increases with the increase in speed. Further, it attains a maximum lateral acceleration value with increase in speed. The H Back and Sedan cars have more or less same type of lateral behavior. The lateral acceleration lies within 0.4 m/s², whereas the two wheeler and motorized three wheeler have high lateral acceleration than the cars i.e. up to 0.8 m/s². However in this case, the SUV cars show very high lateral acceleration as two wheeler and motorized three wheeler, which is most unlikely in general. From the video we observed that, the traffic density is quite high during the time of data collection, hence the lateral maneuverability is high in this case. From result it is observed that, though SUV cars are large in size, the maneuverable capacity is quite high than the H-Back and Sedan cars. Lateral acceleration values reduces (from maximum lateral acceleration values) at speed greater than 10 m/s. This behavior is similar as in case of Kolkata. It is also observed that two wheeler shows the highest lateral acceleration than the other vehicles.

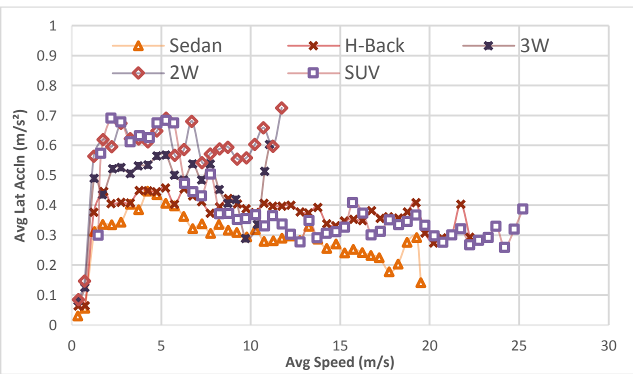


Figure 6 Relationship between lateral acceleration with longitudinal speed of PUNE for all 5 type of vehicles

Analysis of variance (ANOVA) test is conducted to see the significance of all five type of vehicles. It is observed that P_{value} is less than 0.05 and $F_{statistics} > F_{critical}$. Hence, the lateral acceleration for all five types of vehicles is significantly different at 5% significance level. Hence, the null hypothesis is rejected. By the standard error test it is observed that the standard difference between the mean values for H-Back, Sedan is higher than the standard error. Hence mean of lateral acceleration of Sedan and H-Back cars are strongly different from the mean of two wheeler and motorized three wheeler and SUV cars.

Similar plot of the lateral acceleration versus the longitudinal speed for Pune has been shown in Figure 6.

From Figure 6, it is observed that for all class of vehicles, lateral acceleration values are low at near zero speed and it quickly increases with increase in speed. The H Back and Sedan cars have more or less same type of lateral behavior. The lateral acceleration for H-Back and Sedan, lies within 0.4 m/s², whereas the two wheeler and motorized three wheeler have high lateral acceleration than the cars i.e. up to 0.7 m/s², similar to the case of Kolkata. However in this case, the SUV cars show very high lateral acceleration as two wheeler and motorized three wheeler as in case of Mumbai. This is due to the high traffic density during time of data collection, hence the lateral maneuverability is high in this case. From result it can be concluded that, though SUV cars are large in size, the maneuverable capacity is quite high than the H-Back and Sedan cars. It attains quickly high lateral acceleration at lower speed conditions. Similar to Kolkata and Mumbai, lateral acceleration values reduces at speed greater than 10 m/s.

The Analysis of Variance (ANOVA) test for this case indicates that the lateral values of all five vehicle types are significantly different at 5% significance level. The null hypothesis is rejected. By the standard error test, it is observed that the mean of lateral acceleration of Sedan and H-Back cars are strongly different from the mean of two wheeler, motorized three wheeler and SUV cars.

4.2 City Wise Lateral Acceleration Variation For All Vehicle Type

In the present section, a comparative study has been done of all five type of vehicles (SUV cars, Sedan cars, Hatchback, two wheeler and motorized three wheeler) for all three cities - Kolkata, Mumbai and Pune.

It is observed that the lateral acceleration variation of SUV cars for Mumbai and Pune is same whereas the same for Kolkata has very low lateral acceleration. This may be due to the change in driver behavior between these regions. The first region is Mumbai and Pune (neighbor cities) while the other is Kolkata. The traffic and driver behavior are more or less similar in Mumbai and Pune cities as they lie in the same geographical region whereas Kolkata has an altogether different driver behavior than Mumbai and Pune. Hence for similar type of vehicles i.e. SUV, and similar road facilities, the lateral variation is different for both the regions as shown in Figure 7.

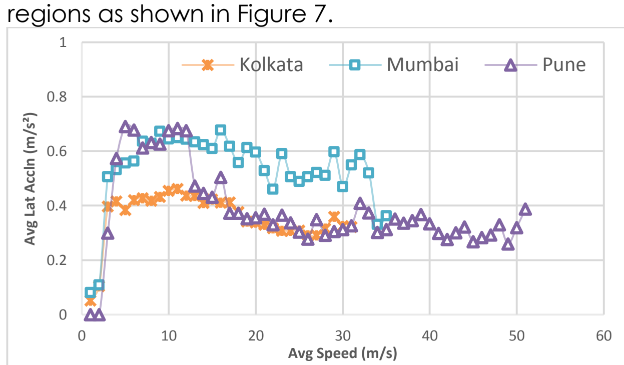


Figure 7 Lateral acceleration Variation of SUV for all three cities

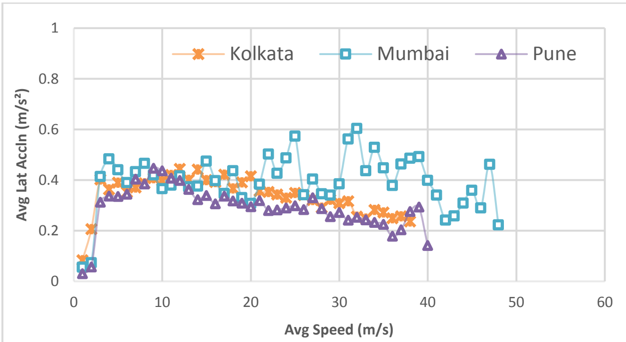


Figure 8 Lateral acceleration Variation of Sedan for all three cities

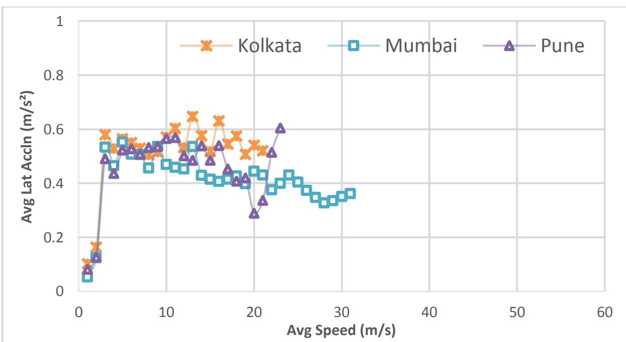


Figure 9 Lateral acceleration variation of Motorized three wheeler for all three cities

From the Analysis of Variance (ANOVA) test, it is observed that the lateral acceleration of SUV for all three cities is significantly different at 5% significance level. Hence, the null hypothesis is rejected. Similarly, the variation in lateral behavior of Sedan cars for all three cities is plotted below in Figure 8.

From the figure, it can be observed that the variation in lateral acceleration of Sedan cars for all three cities is more or less same at lower speed condition (i.e. < 10 m/s) whereas the lateral acceleration variation for Mumbai city is high at higher speed condition (i.e. > 10 m/s). This may be due to the high overtaking man oeuvre of the particular test vehicle at higher speed. Here, the ANOVA test results show that the null hypothesis is rejected. Hence, the lateral acceleration variation is significantly different for all three cities at 5% significance level.

Similar type of results have been observed for the motorized three wheeler vehicles for Kolkata, Mumbai and Pune. The plot of the lateral acceleration versus the longitudinal speed for all three cities is shown in Figure 9. Though the variation is similar for all three cities, the ANOVA test shows that there exists a significant difference in the mean values at 5% significance level.

The lateral acceleration of H-Back and the two wheeler vehicles versus the longitudinal speed shows similar behavior for all three cities as shown in Figure 10 and Figure 11, respectively. The variation of lateral acceleration of H-back and two wheeler is same for Kolkata, Mumbai and Pune. The ANOVA test also concludes that the lateral acceleration values are not significantly different at 5% significance level. Thus, the null hypothesis is accepted. Hence, the mean value is same for the two vehicle types (H-back and two wheeler).

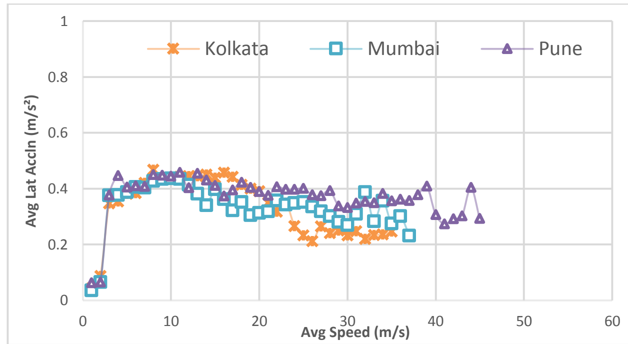


Figure 10 Lateral acceleration variation of H-Back for all three cities.

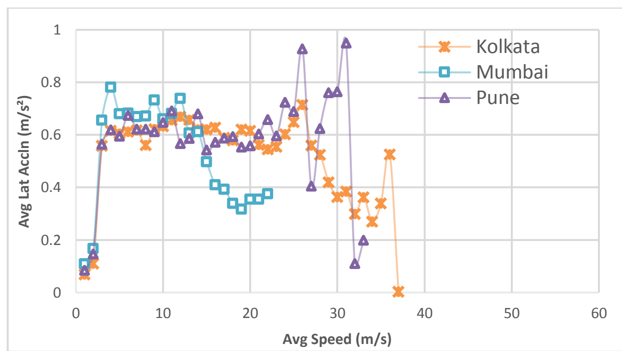


Figure 11 Lateral acceleration variation of two wheeler for all three cities

The lateral behavior of the SUV cars and Sedan cars with the increase in the number of lane have also been observed. The following section justifies the behavior of SUV and Sedan cars with the number of lanes.

4.3 Impact of the Number of Lanes on Lateral Acceleration

Data has also been collected for SUV and Sedan cars with the similar type of instrument set up on 6 lane divided road (Kolkata) and 8 lane divided road (Mumbai). The variation in lateral acceleration with the speed for Kolkata city (4 lane and 6 lane) is plotted below.

From Figure 12 and Figure 13, it is observed that, the lateral acceleration of SUV cars is high for 4 lane divided roads (2 lane each) than the 6 lane divided roads (3 lane each). This may be due to the low traffic density in the 6 lane roads than the 4 lane roads. As the traffic density is low, the vehicles feel free to move. Hence, the lateral maneuver is less. Whereas in the case of Sedan cars the lateral acceleration variation is more or less similar. From the ANOVA test, it is observed that the $P_{value} > 0.05$, hence the null hypothesis is accepted. This indicates that there is no significant difference between the lateral acceleration variation of 4 lane and 6 lane roads. Similar study has been conducted for the 4 lane and 8 lane roads of Mumbai city for SUV and Sedan cars.

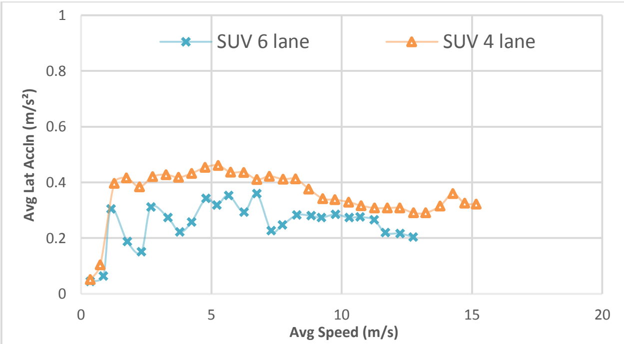


Figure 12 Lateral acceleration variation of SUV cars for different number of lanes of KOLKATA.

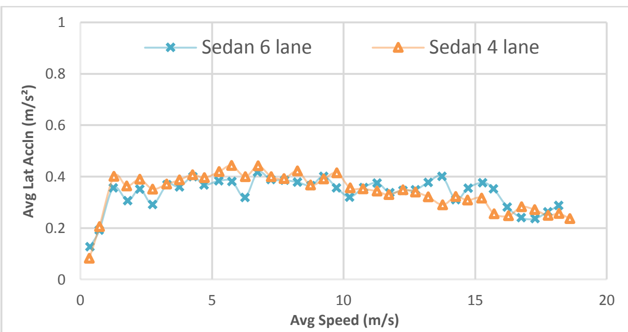


Figure 13 Lateral acceleration variation of Sedan cars for different number of lanes KOLKATA.

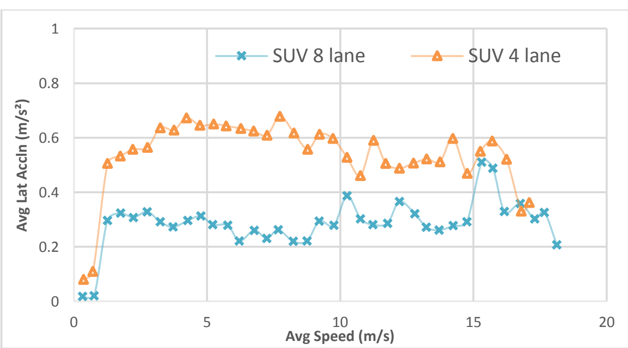


Figure 14 Lateral acceleration variation of SUV cars for different number of lanes of MUMBAI.

From the Figure 14 and Figure 15, it is observed that the lateral acceleration of SUV and Sedan cars are very high for 4 lane divided roads (2 lane each) than the 8 lane divided roads (4 lane each). Though the space availability for vehicle movement is more in case of 8 lane roads, the vehicle travels very smoothly than the 4 lane roads. This may be due to the reduction in density of 8 lane roads as in case of Kolkata city.

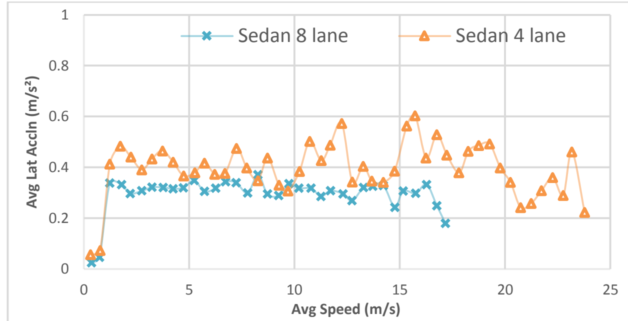


Figure 15 Lateral acceleration variation of Sedan cars for different number of lanes of MUMBAI

5.0 CONCLUSIONS

In this paper, the lateral characteristic of the vehicle with respect to the vehicle's speed is collected for five different types of vehicle (H back car, Sedan car, SUV car, two wheeler and motorized three wheeler). The effect of the vehicle's speed as well as the vehicle type on the lateral behaviour is studied for the three metropolitan cities of India (Kolkata, Mumbai and Pune). It is observed that there exist an inverse relationship between the speed and the lateral characteristics except at lower speeds (speed between 2 m/s to 10 m/s). The lateral acceleration is zero at zero speed and it gradually increases to the highest value with the increase in the speed up to 3. After 3 m/s speed, the lateral behaviour remains more or less constant with increase in the speed of up to 10 m/s and decreases with the further increase in the speed. The vehicle type also affects the lateral behaviour. The main findings of this study are summarized as follows;

- Lateral acceleration is very high in case of two wheeler and lower in case of SUV cars.
- The high variation in lateral acceleration of SUV cars for Kolkata city from the Mumbai and Pune city is due to the variation in Driver behaviour and traffic behaviour between the two regions.
- All three types of cars have very low lateral movement than the two wheeler and Motorized three wheeler i.e. up to 0.4 m/s².
- The Lateral manoeuvre of vehicles on the road decreases with the increase in size of the vehicle.
- Though SUV is large in size, the manoeuvre capacity is very high than other vehicles. It can quickly attain high lateral acceleration at very lower speed also.
- Comparing to all three cities, it has been observed that the Mumbai and Pune cities have more or less similar pattern of lateral behaviour than the Kolkata city. This proves that, the change in region and driver behaviour also effect the lateral movement of traffic.
- Number of lanes on the road also effects the lateral movement of the vehicles.
- The lateral acceleration of SUV cars for Mumbai and Kolkata city is very high in case of 4 lane divided roads (2 lane each), than in case of 6 lane

divided roads (3 lane each) and 8 lane divided roads (4 lane each). Sedan cars of Mumbai city also exhibit same kind of result.

- Whereas the Sedan cars for Kolkata city have same lateral movement for both 4 lane and 6 lane divided highways. This may be due to the similar type of density on both the roads (Observed from the video VBOX data).

Lateral characteristic of the traffic is one of the important characteristics in case of no lane discipline road. Due to the high lateral movement, there exists frequent accidents and congestion in Indian roads. Hence to avoid these, lane discipline is an important criteria to be considered.

References

[1] Felip, E., and Navin, F. 1998. Automobiles on Horizontal Curves. *Transportation Research Record*. 0482(50).

[2] Halmark, S. 2009. Relationship between Speed and Lateral Position on Curves. *Centre for Transportation Research and Education, Iowa State University*.

[3] Hadri, A. El., Cadiou, J.C. Beurier, G. and M'Sirdi, N.K. 2001. Vehicle/Road Interaction and Tyre lateral Performance Identification. *IEEE International Workshop on Robot and Human Interactive Communication*. 0:7803-7222.

[4] Brackstone, M., McDonald, M. and Sultan, B. 1999. Dynamic Behavioral Data Collection Using an Instrumented Vehicle. *Transportation Research Record*. 2535(9).

[5] Sarosh, I. K. and Pawan, M. 1998. Modelling Heterogeneous Traffic Flow. *Transportation Research Record*. 0906(234).

[6] Santel, G. 2010. Lane Driver Behavior. *10th Swiss Transport Research Conference. STRC*.

[7] Reymand G. and Kemeny A. 2001. Role of Lateral Acceleration in Curve Driving: Driver Model and experiments on Real Vehicle and Driving Simulator. *The Journal of the Human Factors and Ergonomics Society.* Vol. 43(3) : 483-495

[8] Lennie, S. C. and Bunker, J. M. 2005. Using Lateral Position Information as a Measure of Driver Behavior around MCVs. *Road & Transport Research*. 14(3): 62-77.

[9] Rosey, F. and Auberlet, J. M. 2012. Trajectory Variability: Road Geometry Difficulty Indicator. *Journal of Safety Science*. 50: 1818-1828.

[10] Lewis-Evans, B. and Samuel. G. C. 2006. Explicit and Implicit Process in Behavioral Adaption to Road Width. *Journal of Accident Analysis and Prevention*. 38: 610-617.

[11] Stodart, B. P. and Donnel, E. T. 2008. Speed and Lateral Vehicle Position Models from Controlled Nighttime Driving Experiment, *Journal of Transportation Engineering*. 134(11).

[12] Antonson, H., Mardh, S., Wiklund, M., Blomqvist, G. 2009. Effect of Surrounding Landscape on Driving Behavior: A Driving Simulator Study. *Journal of Environmental Psychology*. 29: 493-502.

[13] Dijksterhuis, C., Brookhuis K. A. and Waard, D. D. 2010. Effects of Steering Demand on Lane Keeping Behaviour, Self-reports, and Physiology. A Simulator Study. *Journal of Accident analysis and prevention*, 43(2011): 1074-1081.

[14] Ritchie, M. L., McCoy, W. K. and Welde,W. L. 1968. A study of the Relation between Forward velocity and Lateral Acceleration in Curves during Normal Driving. *The Journal of Human Factors and Ergonomics Society*. 10 : 255-258

[15] Odhams, A. MC. and Cole, D. J. 2004. *Models of Driver Speed Choice in Curves*. AVEC.

[16] Mahapatra, G. and Maurya, A. K. 2013. Study of vehicles lateral movement in non-lane discipline traffic stream on a straight road. *Procedia - Social and Behavioral Sciences*. 104: 352-359.

[17] Elisabeth, A. 2003. Lateral Position Detection using a Vehicle Mounted Camera. *Institutionen for Systemteknik, Linkoping*. 3417.

[18] Yang, J.S. 2012. Estimation of Vehicle's Lateral Position via Lucas Kanade Optical Flow Method. *WSEAS Transaction on Systems*. 11(8).