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Identification of different vehicle-following manoeuvres for heterogeneous weak-lane disciplined traffic condition from vehicle trajectory data

Kavitha Madhu¹, R Sivanandan² and Karthik K Srinivasan²

¹ Associate Professor, Department of Civil Engineering, TKM College of Engineering, Kollam, Kerala

² Professor, Transportation Engineering Division, Department of Civil Engineering, Indian Institute of Technology Madras, INDIA

E-mail: kavithamadhu03@gmail.com

Abstract. Indian traffic can be considered as mixed and heterogeneous due to the presence of various types of vehicles that operate with weak lane discipline. Consequently, vehicles can position themselves anywhere in the traffic stream depending on availability of gaps. The choice of lateral positioning is an important component in representing and characterising mixed traffic. The present study aims to develop a methodology to extract the trajectory of vehicle for heterogeneous non-lane based traffic condition. To study the movement pattern of vehicle types and to explore the vehicular behaviour and its reaction to different traffic environment, it is essential to extract the trajectory data of vehicles. Therefore, a semi-automated tool using python's graphical user interface is developed to extract the vehicle trajectory. The field data provides evidence that the trajectory of vehicles in Indian urban roads have significantly varying longitudinal and lateral components and the traffic flow characteristics of each vehicle types vary from one another. Present study analysis the variation in driving behaviour of vehicle with lateral position characteristics. It has been found that the following behaviour of vehicles varies with the lane position and the traffic parameters of each lane differ from each other.

1. Introduction

The key element in developing driving behaviour models is to understand and analyse the interactions between the vehicles. Identifying and analysing exact interactions between various classes of vehicles in the traffic stream is essential for increasing the accuracy and realism of microscopic traffic flow modelling. Indian traffic scenario is mixed and heterogeneous which consist of numerous vehicle types with varying static and dynamic characteristics sharing the same road space under weak lane disciplined state. This state of traffic creates complex vehicular interactions which requires the thorough study of vehicular movement patterns. The way in which vehicles act and react to specific traffic environment need to be studied carefully because this becomes the basis for developing car-following models, acceleration models, lane changing models which in turn being used to evolve traffic simulation software.

From field data it is obvious that in mixed traffic condition, the vehicle following manoeuvre is not strict as in homogeneous and lane disciplined conditions and neighbouring vehicles ahead of a given vehicle and those adjacent to it could also influence the subject vehicles choice of position, speed and acceleration. In addition, due to variations in size and dynamic capabilities of vehicles, multiple leaders are also observed in some cases. Therefore, to study the behaviour of mixed traffic condition the trajectory of vehicle need to be extracted and a tool need to be devised for extraction.



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Of the cluster of vehicles surrounding the subject vehicle, the adjacent vehicle plays an important role in deciding the longitudinal response. Since the imposition of lane-based movement is absent which results in the positioning of vehicles on available gaps that instigates the role of an adjacent vehicle. Traffic flow is assumed to be lane-based movement if the lateral positions of all the vehicles in a lane are normally distributed [1]. In such a case, every vehicle moves through the middle of lane one behind the other leading to the car-following condition. Whereas in mixed traffic vehicles can place themselves anywhere in the traffic stream depending on availability of gaps irrespective of lane separation. These situations lead to a condition where the nearby vehicles in the close vicinity either in the same lane or in the adjacent lane imparts influence on driving decisions. Not only the presence of adjacent vehicles but the orientation of them also has a role in deciding the longitudinal response of subject vehicle.

2. Literature review

Driving behaviour models like car-following/acceleration models and lane changing models depicts how the driver behave at different traffic situations [2]. Data at microscopic level is vital for studying vehicular interactions and modelling driving behaviour models. Theoretical concept of these models has been studied in detail for the past decades but the calibration and validation of these models using observational data is studied less [3].

The main reason for the lack of study in this field is due to unavailability of vehicle trajectory data in time-space scale. Quite a few studies have been carried out in this regard under homogeneous traffic condition that consist mainly of cars of uniform size which follow lane discipline. FHWA's next generation simulation project is one such attempt which have consolidated vehicle trajectories from major US roads and is made available to public [4]. This data has been widely used for the purpose of calibration and validation of driving behaviour models in homogeneous condition [5-8]. But limited initiatives have carried out in this regard under mixed traffic condition due to enormous effort and time associated with the whole process of data collection. Since mixed traffic condition is in a chaos state, the data collection at individual vehicle level is quite demanding in terms of time and effort involved.

Several previous studies have collected data at microscopic level but the scopes are limited. Calibration and validation of driving behaviour models under mixed traffic condition has taken place in macroscopic level considering flow, speed and density parameters matching the actual with the simulated data [9-11]. But calibration at macroscopic level will reduce the level of detailing required in validation and calibration. However, calibration and validation of driving behaviour model is still inadequate in mixed traffic condition at microscopic level because of non-existence of data sets. The common trajectory extraction tool used for homogeneous condition like Autoscope and Traficon does not hold good for Indian traffic because of wide variety of vehicles sharing the same road space with varying static and dynamic characteristics that seldom follow lane discipline. Some of the tools that have been used for trajectory extraction in mixed traffic conditions are Trajectory Extractor , TRAZER and Traffic Data Extractor(TDE)[12].

But the public availability of trajectory of vehicles for mixed traffic condition are limited due to the enormous time and cost spent in collecting and extracting data. Therefore, the objective of present study is to develop a semi-automated method by which the data such as vehicle type, vehicle dimensions along with position, speed and acceleration of vehicles in longitudinal and lateral directions at every instant of time can be recorded.

3. Data collection and camera calibration

The stretch identified for video data recording is at Mount Poonamalle road in Porur, Chennai, India. The stretch selected is a six-lane divided highway with three lanes in each direction. An eleven-storey apartment is selected as the vantage point for placing the video camera.

The data was collected during peak and off-peak hours from morning till evening, selecting 9am to 11am as morning peak hours, 1pm to 3pm as afternoon off-peak hours and 4pm to 6pm as evening peak

hours. The peak and off-peak hours were identified from preliminary study and data available from GPS devices fitted in MTC (Metropolitan Transport Corporation) buses.

The initial step involved in microscopic traffic data collection process is camera calibration and perspective transformation. The length of stretch considered was 250 m which was divided into blocks of 10 m long in longitudinal direction and 1 m wide in lateral direction. Total of 275 blocks were selected and the details of grids are depicted in Figure. 1. The ground distance of each blocks needs to be measured from the camera set-up. The camera was set at an angle of adequate visibility and zoom. Then data collection persons were made to stand at the corner points of each block in the grid. This will help in calibration of camera and is used for converting the pixel coordinates to ground coordinates. Once the camera is fixed then care should be taken so that no alteration happens to the camera angle, zoom and pan until the data collection process is completed.



Figure 1: Grid-lines in longitudinal direction and lateral direction used for camera calibration

Later the video was played, and the pixel coordinates of the points were found using Irfan-view software and the corresponding coordinates were used to draw grid-lines in Autocad-2013. The grid thus created was overlaid over the video using Adobe Premiere Pro CS6 at a frame rate of 25 frames per second. The superimposed video is then converted into frames at the rate of 1 frame per second. Extracting vehicle trajectory for heterogeneous traffic is quite demanding. There are several methods like manual, semi-automated and automated tools that can be used for this purpose. The present study uses a graphical user interface in python to extract the pixel coordinates of vehicle positions from each frame. Screen-shot of a frame opened in GUI (Graphical User Interface) of python is shown in Figure.2. A file named "output.txt" is created in the same directory of frames which records all the entry made by the user. The frames will get loaded in GUI so that the user can start clicking on a distinguishable point on the vehicle when it is present on each frame. Wherever the user clicks on the frame its x, y pixel coordinates will get recorded in the "output.txt" file along with frame number. After saving the data of current vehicle, the user can start tracking the next consecutive vehicle and can continue to the last vehicle in the frame.

There are 6 vehicle types considered in the study and are as follows:

- (i) Motorised Two-Wheeler (MTW)
- (ii) Passenger Car (Car)
- (iii) Bus
- (iv) Heavy Commercial Vehicle (HCV)

- (v) Light Commercial Vehicle (LCV)
- (vi) Auto-rickshaw/ Three- wheeler.

The initial set of extracted data contain the details such as vehicle type, time frame, longitudinal and lateral pixel coordinates which are sorted with respect to time. To convert the pixel coordinates (X, Y) to world coordinates the following steps were followed. First step include the determination of Correction fractions C_X and C_Y . Correction factor along Y direction can be determined using the equations Eq. 1, Eq. 2 and Eq. 6. Similarly, correction factor along X direction can be determined using equations Eq. 3, Eq. 4 and Eq. 5.

$$C_{Y1} = \frac{100}{\sqrt{(X_3 - X_1)^2 + (Y_3 - Y_1)^2}} \quad (1)$$

$$C_{Y2} = \frac{100}{\sqrt{(X_4 - X_2)^2 + (Y_4 - Y_2)^2}} \quad (2)$$

$$C_{X1} = \frac{1000}{\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}} \quad (3)$$

$$C_{X2} = \frac{1000}{\sqrt{(X_4 - X_3)^2 + (Y_4 - Y_3)^2}} \quad (4)$$

$$C_X = \frac{C_{X1} + C_{X2}}{2} \quad (5)$$

$$C_Y = \frac{C_{Y1} + C_{Y2}}{2} \quad (6)$$

Where (X_1, Y_1) , (X_2, Y_2) , (X_3, Y_3) and (X_4, Y_4) are the coordinates of four corners of a block as shown in Figure.3. C_X and C_Y are the correction factors in X and Y direction respectively.

Second step include the identification of the block which contain $(X, Y)_{pixelcoordinate}$. If $(X, Y)_{pixelcoordinate}$ is contained inside the m^{th} block as shown in Fig.3, then Eq. 7 to Eq. 13 were used to convert $(X, Y)_{pixelcoordinate}$ to $(X, Y)_{worldcoordinate}$

$$m = \frac{Y_2 - Y_1}{X_2 - X_1} \quad (7)$$

$$Y_a = \frac{Y_1 + Y_3}{2} \quad (8)$$

$$X_a = \frac{Y_a + mX - Y}{m} \quad (9)$$

$$X_X = X + X_1 - X_a \quad (10)$$

$$Y_X = Y + Y_1 - Y_a \quad (11)$$

The longitudinal and lateral world coordinates of points X and Y are determined using equations Eq.12 and Eq. 13 respectively.

$$X_{worldcoordinate} = \sqrt{C_X(X - X_a)^2 + C_Y(Y - Y_a)^2} \quad (12)$$

$$Y_{worldcoordinate} = \sqrt{C_X(X - X_X)^2 + C_Y(Y - Y_X)^2} \quad (13)$$

Where (X, Y) is the pixel coordinate, m is the slope of line, (X_X, Y_X) and (X_a, Y_a) are the midpoints of lines in Y and X direction respectively.

After extracting the coordinates of each vehicle at time-space scale, the data need to be smoothed to control the errors incurred due to missing observation, occlusion due to larger vehicles and to reduce the measurement errors. Data smoothing is also required to compute the secondary variables like speed and acceleration in lateral and longitudinal direction along with shift. Position of vehicles at two successive points divided by the time difference gives the instantaneous speed. The acceleration rates are obtained by the ratio of instantaneous speed to time difference at two consecutive points. These variables can be further used to determine the macroscopic variables like flow, density and stream speed.

4. Variation in vehicle composition across lanes

The highway selected for the traffic analysis in the present study is having three lanes as shown in Figure.4 and the fluctuations in vehicle composition of these lanes are examined in this section. The traffic volume in the study stretch was found to be 7050 vehicles per hour and the vehicle composition is given in Figure.5d with majority being motorised two-wheeler (MTW). 71% of the traffic volume consist of MTWs followed by 24% of passenger cars. MTWs and passenger cars together constitute the major share of traffic volume. The remaining 5% consist of 2% of auto-rickshaws (Three-Wheeler), 2% of LCVs and 1% of buses and HCVs.

As shown in Figure.4, the traffic composition in each lane is analysed separately and is given in Figure.5. Motorised two-wheeler (MTW) composition is more concentrated on shoulder lane and middle lane. But if passenger cars are considered, the major share of cars are moving through middle and median lane. At median lane the proportion of cars and MTW are almost alike whereas there exists much difference in other two lanes. Even though the composition of auto-rickshaw is small, they are mainly positioned in shoulder and median lanes. The percentage of auto-rickshaw in median lane is less than 1%.

The vehicle composition on shoulder lane, middle lane and median lane is depicted in Figure.5a, Figure.5b and Figure.5c respectively. The plots demonstrate that the vehicle composition on these lanes are entirely different from one another. The shoulder lane has major portion of two-wheeler. The passenger cars proportion on shoulder lane is minimum compared to other two lanes. The LCVs, Buses and HCVs are uniformly distributed on all the three lanes. The reason for this variation in distribution in composition is due to the fact that the right most lane is mostly used by the fast-moving vehicles which prefers adequate freedom in manoeuvres. Therefore, major portion of the passenger cars are more concentrated on the median lane. Since there are no bus stops present in the stretch, buses are mostly moving through the middle of the road. So the lane-wise traffic composition study becomes relevant for numerous traffic management measures like traffic segregation, dedicated lanes, tidal flow operations and many more.

5. Lateral shift and vehicle trajectory pattern of vehicle types

In heterogeneous traffic condition with weak lane discipline, the vehicles can position themselves anywhere in the traffic stream depending on availability of gaps. In a traffic scenario where the vehicles are restricted from performing free manoeuvres, two-wheelers still have space for manoeuvring through the gaps available between the vehicles. When the vehicles are in free flow condition, the amount of lateral displacement will be less. But as the V/C ratio increases vehicle tries to shift to nearby lateral positions often so that they can have both speed advantage and gap advantage. Such features of traffic flow and wide variations in vehicular characteristics have been accounted using the parameter “ Shift ”. The peculiarity of Indian traffic which can either be called as its benefit or drawback is the lack of lane discipline. Because of this lack of lane discipline vehicle can position themselves anywhere in the traffic stream based on gap availability, which gives the benefit of operating under maximum capacity. But at the same time this has got long term issues like if traffic congestion occurs, then the duration required to clear the block is extensive. This can also lead to chaotic vehicle movement patterns and can lead to increased accident rates.



Figure 2: Screen-shot of a frame showing the study stretch in python's GUI (graphical user interface)

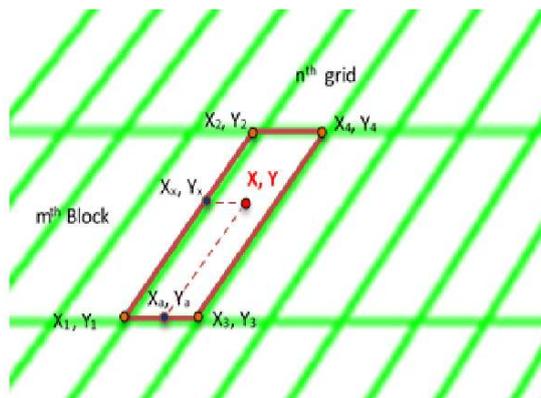


Figure 3: Details of mth block, nth grid showing the coordinates of four corners and midpoints



Figure 4: Lane positions in the study stretch - shoulder lane, middle lane and median lane

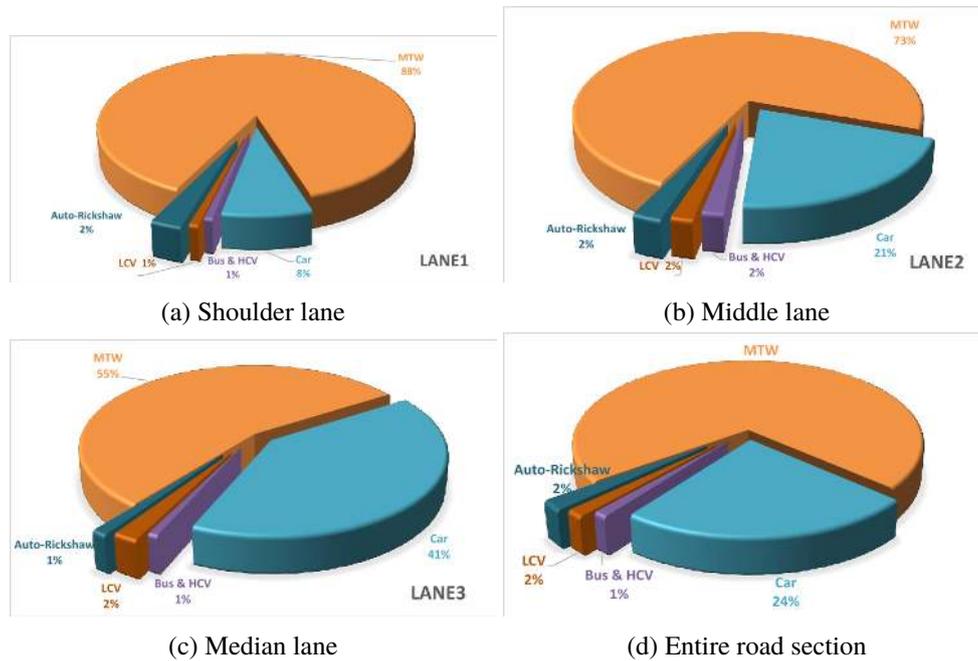


Figure 5: Vehicle composition for the entire road section and for each lanes separately

If gap is available to proceed the vehicle at any instant of time can shift themselves to nearby positions thereby every instant of time a vehicle moves in a 2-dimensional plane which has got longitudinal and lateral component of speed along the road. This shifting nature of vehicle varies from vehicle to vehicle depending on its static and dynamic characteristics. This variations in vehicular movement pattern shows much difference in their trajectories and is discussed in this session. Figure. 6 shows the difference in trajectories of different vehicle types which are present on the same road stretch during the same interval of time.

Shift is used to explain the amount of lateral shift with respect to the longitudinal path between two consecutive time steps. Shift is defined as the ratio of lateral to longitudinal position from previous to present time step and is given in Eq. 14

$$Shift_i(t) = \tan^{-1} \frac{lat_i(t) - lat_i(t-1)}{long_i(t) - long_i(t-1)} \quad (14)$$

where, $lat_i(t)$ is the lateral position at current time step, $lat_i(t-1)$ is the lateral position at previous time step, $long_i(t)$ is the longitudinal position at current time step, $long_i(t-1)$ is the longitudinal position at previous time step, t is the time step which is increasing at the rate of 1 second.

The summary statistics of the parameter shift in degrees is shown in Table 1. The vehicle in heterogeneous mixed traffic condition have a constant tendency to change its position and lane. Position shift is crucial than lane changing in weak lane-disciplined traffic condition. The shift is maximum for two-wheeler followed by auto-rickshaw and passenger car. Whereas the buses, HCVs and LCVs almost have the same values and tries to follow the same path than deviating its position at each time step.

The motorised two-wheeler (MTW) have frequent shifting tendency which is explained by the trajectory shown in Figure 6c. Because of its advantages in its dimension and acceleration characteristics MTW tend to shift its position frequently to attain better speed and manoeuvrability. Whereas the vehicles with wider dimensions usually have lesser chance to shift themselves to adjacent positions because of the constrains imposed by the presence of surrounding vehicles. Figure 6a shows the trajectory of a passenger car. Compared to that of MTW the lateral position shift is less for passenger car for its entire tracking length of 250 m.

Table 1: Descriptive statistics of lateral Shift in degrees

Vehicle Type	Extreme Values	Average	Std. Deviation
Car	5.328	1.746	0.796
Bus	3.761	1.635	0.546
HCV	3.713	1.663	0.673
LCV	3.885	1.676	0.593
MTW	9.737	1.935	0.976
Auto-Rickshaw	6.998	1.835	0.835

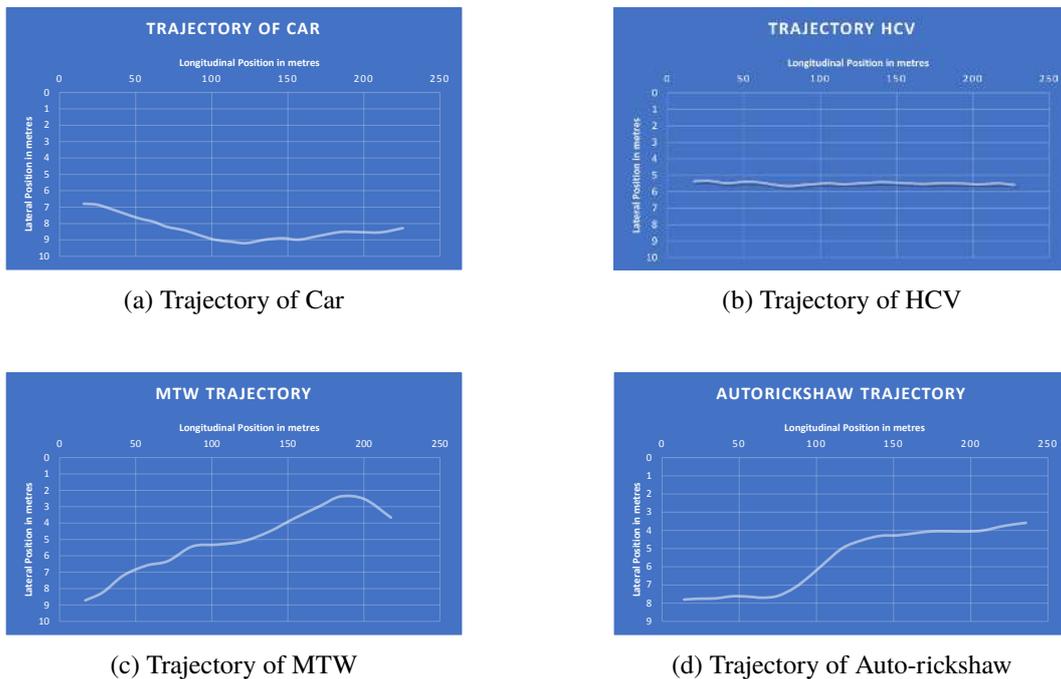


Figure 6: Trajectory of vehicle types in study stretch - Car, HCV, MTW, Auto-Rickshaw

Figure 6b shows the trajectory of HCVs which indicate that the shifting characteristics of HCV is different from that of passenger car and MTW. HCVs try to maintain the same lateral position for its entire longitudinal tracking length. The reason may be because of its larger size and lesser manoeuvring capability, they usually prefer to move in the same lane than shifting across the lanes. Because of this reason the HCVs like buses, trucks and tempo travellers try to maintain the same lateral position along its path.

6. Identification of different vehicle-following manoeuvres

The major challenge in modelling mixed traffic condition is the numerous and complex interactions between vehicles that every user experience on roads. This section aims to develop and analyse time gap distribution models and quantify it by lead lag pair, manoeuvre type and lateral position characteristics in heterogeneous non-lane based traffic. This section tries to classify manoeuvres based on vehicle type and lateral overlap between the lead and lag vehicle and to fit time-gap distribution for each classified manoeuvre types. The concept of Lead-Lag vehicle and longitudinal and lateral gap is sketched in Figure.7.

Eight kinds of manoeuvres are identified based on the size and placement of lead and lag vehicle.

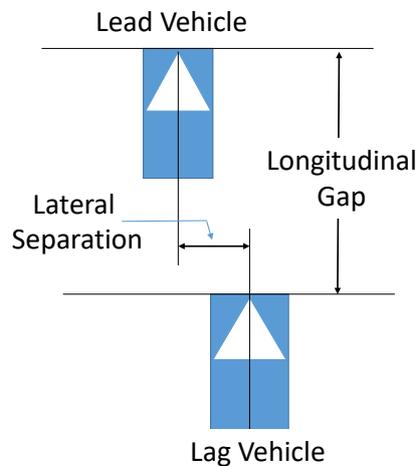


Figure 7: Lateral gap and longitudinal gap

Depending on the size of leader and follower there are three basic sub divisions like lead vehicle size larger than lag vehicle size, then lead vehicle smaller than lag vehicle and the third one is if both are of same size. Each of these three categories are further divided based on the relative lateral position between the lead and lag vehicle. If leader's lateral dimension is substantially larger than the follower, then three kinds of manoeuvres can be spotted namely strict (if lateral gap is less than 0.5 m), contained staggered (if lateral gap is more than 0.5m and the lag vehicle is contained within the width of leader) and partially staggered (if lateral gap is more than 0.5 m and the lag vehicle is not contained within the width of leader) as shown in Figure 8. But if leader width is smaller or equal to the lag vehicle it can have only two kinds of manoeuvres namely strict and staggered because in that case lag vehicle cannot be contained within the width of the leader. If any of these seven conditions are not satisfied then the vehicles are said to be in the non-overlapping state which is the eight manoeuvre.

From these eight types, manoeuvre 8 that is non-overlapping is having maximum occurrence of 73% followed by manoeuvre 7 of 9%, then manoeuvre 6 and 5 having 6% each followed by manoeuvre 2 of 3 % and all the other manoeuvres 1,3 and 4 has got only 1% each share on the overall data. This clearly shows that the vehicle always follows the leader in a staggered or non-overlapping fashion. The reason may be vehicles prefer to move freely without being contained by the leader. On doing so it is having maximum manoeuvrability. The lack of lane discipline, weak enforcement and non-identical vehicle sizes may also contribute to this factor. Strict following case is the minimum of the given combinations. So this shows the time headway measurement based on former definition can cater only a small percentage (8%) Strict manoeuvres (manoeuvre 1,4 and 6). So the use of established concepts in simulation modelling like headways, car following etc. are not adequate to capture the Indian traffic.

ANOVA analysis is used to test whether the time gap data for each of these manoeuvres are statistically different. ANOVA is usually done to check the difference in means of data sets for which the basic assumption is that the variance should be same for all the data sets. To assess the equality of variances Levene's test was done that gave a p-value of $4.135e-11$ which is less than the 5% significance level indicating the rejection of null hypothesis saying variances are not equal. So a one way test called Welch's F test was performed and found that the p value is $2.2e-16$ which is again less than 5% level of significance. Thereby the null hypothesis of "all means are equal" is rejected. This shows that there is significant difference in means and variances of time-gaps classified based on manoeuvres. The statistical test results highlight the need to explicitly capture the differences across different manoeuvre types. Therefore, the observed time gaps are classified into different categories based on lead-lag vehicle types and manoeuvre types and the time gap distribution for each category is obtained. Several trial

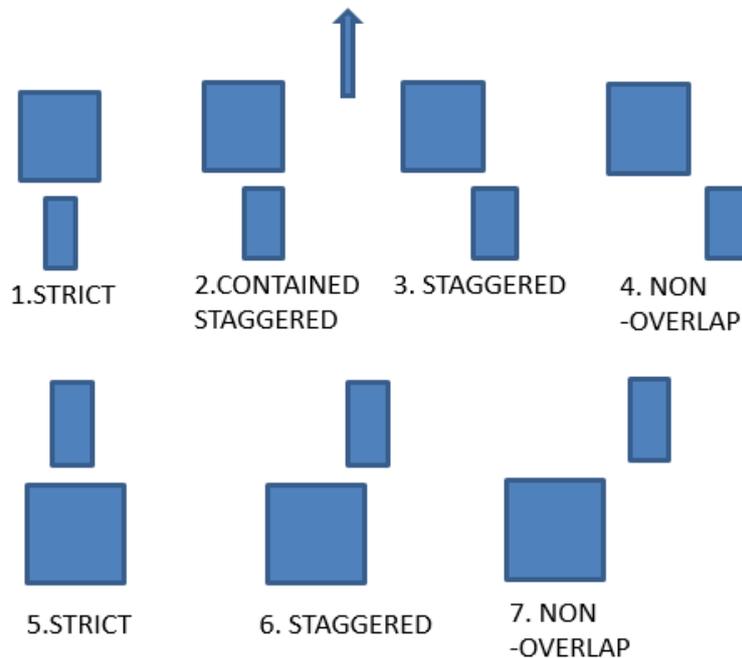


Figure 8: Vehicle-Following manoeuvres identified from empirical data

distributions were considered for each class and the best fitting distribution estimated using maximum likelihood procedure and the goodness of fit identified using K-S test at the 5% level of significance. Almost for all the manoeuvres, time gaps were found to fit the GEV distribution but with different parameters. Considering the time gap distribution for vehicle pairs, except Heavy Vehicle(HV)-Small Vehicle (SV) and Auto-Car combination others are fitting GEV distribution. Weibull distribution can be used to model HV-SV time-gaps and exponential distribution for Auto-Car time gaps.

7. Conclusion

This paper focused on developing a methodology for extracting vehicle trajectory data under mixed traffic condition. A semi-automated tool was developed using python graphical user interface to extract the position coordinates of vehicle at every instant of time. The data was managed to arrive at instantaneous speed, acceleration and deceleration of vehicles along longitudinal and lateral directions.

The vehicle in heterogeneous mixed traffic condition have a constant tendency to change its position which is explained by the parameter called Shift. Shift is highest for two-wheeler, auto-rickshaws and cars while the buses, HCVs and LCVs follow the same path.

From the present study, it is found that the vehicle types are not uniformly positioned over the entire road width. Vehicle composition for each lane differs considerably from the other. The choice of lateral positioning is another important component in representing and characterising mixed traffic condition. The field data provides evidence that the trajectory of vehicles in Indian urban roads have significantly varying longitudinal and lateral components. The vehicle trajectory data possess considerable amount of speed, acceleration and deceleration in lateral direction which shows the need for incorporating the aspect of lateral movement theory into the driving behaviour models.

The trajectory data can be used for defining and classifying the vehicle-following manoeuvres in mixed traffic condition. It has been found that the vehicle following behaviour in heterogeneous lane-less

movement is significantly different from the homogeneous lane-based movement. Most of the time lag vehicle prefer to follow the leader in staggered or non-overlapping following condition and each following manoeuvre is significantly different from one another. Therefore the different following manoeuvres need to be incorporated into the modelling and simulation of mixed traffic flow for making it more realistic and reliable.

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