Exploratory data analysis of lateral clearance between vehicles at signalized intersection with weak lane discipline

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Abstract. Mixed traffic and weak lane-based driving habits of drivers in developing countries like India pose a significant challenge to a precise analysis of traffic condition and behavior. For weak lane disciplined mixed traffic conditions observed in India, the lateral driving behavior parameters are pivotal in assessing and analyzing the traffic proper effective monitoring, management and operations. This study focused on exploring the lateral safety spacing maintained by vehicles observed at signalized intersections. The results show that the lateral clearance maintained by different vehicle classes while interacting with the vehicle travelling abreast to the subject vehicle is statistically different. The lateral clearance maintained by vehicle classes on the left and right sides is also significantly different. However, similar lateral clearance values can be considered for modelling for similar vehicle class combinations, but different values need to be considered for interactions between different vehicle classes.

Keywords: Signalized Intersection, Weak Lane discipline, Lateral clearance, Mixed traffic conditions, Lateral traffic behavior

1. Introduction

Unprecedented vehicular growth (around 8% in India) has resulted in considerable traffic and travel growth on the roads of metropolitan cities and has subsequently resulted in vehicular delays, long queues, and traffic congestion [1]. The congestion is often visible at the junctions where traffic from two or more approach roads intersects. Based on the requirement (demand) and the available warrants, different traffic signals are provided at the intersection as a key instrument to manoeuvre the traffic on its desired path facilitating safe and smooth traffic operations [2], [3]. Signalized intersections have become vulnerable to complex vehicular manoeuvres, movements, and interactions. The interaction is even more complex when weak lane disciplined mixed traffic conditions generally observed in the developing countries like India are also considered, resulting in excessive delays, conflicts, and accidents [4]. Hence, models

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based on microscopic aspects that explore the intricacies involved in the interaction of different leader-follower vehicle class combinations could better model disordered traffic, specifically at signalized intersections [2], [3].

However, the values of driving behavior representative parameters (DBRP) that can facilitate robust calibration & validation of different driving behavior models, and would govern these models' efficacy in modelling traffic behavior are not robustly available [5], [6]. The DBRP values for vehicular interactions as a leader and follower observed at signalized intersections with weak lane discipline traffic are described in detail by the current authors in previous study [3]. However, the study only considered the longitudinal interactions and driving behavior parameters strictly. Details about parameters related to lateral behavior are not discussed. Considering the inherent traffic nature of weak lane disciplined mixed traffic, lateral behavior of vehicles significantly affects the traffic operations, efficiency and safety aspects [5], [7].

The lateral driving behavior of the vehicles is generally attributed with lateral gap acceptance and lane changing. However, for weak lane disciplined traffic another aspect of lateral clearance or distance maintained by the vehicles is also pivotal. Lateral clearance (LC) is the "sidewise safety spacing maintained by a vehicle with neighbouring vehicles when it travels through a traffic stream" [7]. Since, unavailability of proper or safe lateral clearance value resulting due to weak lane discipline and laterally moving vehicles shall force the subject vehicle driver to either decelerate or avoid moving further, hence further disrupting the traffic. Therefore, the present study performs an exploratory analysis of the lateral clearance maintained by different vehicle classes at signalized intersections with weak lane disciplined traffic.

2. Data Collection and Processing

2.1 Site Selection and Data Acquisition

A three legged isolated fixed cycle length signalized intersection located in Jaipur the state capital of Rajasthan , India is selected. Road dimensions and reference points for data collection and extraction were measured manually during the off-peak hours of the night. The approach road has a width of 9.5m which includes 3 lanes of 3.1 meters each. The intersection is controlled using a fixed time three-phase signal with Red-Green-Amber-Red type signaling. The video recording of 250 meters of road stretch at upstream of stop-line and 80 meters downstream of stop-line simultaneously was done from a high vantage point on a working weekday with clear and normal weather. The data extraction process detailed in the available literature [3], is followed in the present study for acquiring the trajectory data for further analysis.

2.2 Lateral Interactions.

Drivers in lane disciplined and almost homogenous traffic conditions usually observed in developed nations, primarily interact only in longitudinal dimension, i.e., as a leader and follower vehicle. The lateral interaction of a subject vehicle is observed during lane changes. However, in weak lane disciplined mixed traffic conditions, the subject vehicle is interacts simultaneously in longitudinal and lateral directions. During lane changes, the subject vehicle driver considers the longitudinal and lateral gap available to him in addition to different vehicle classes adjacent to it, and the speeds of the vehicle [8]. Hence the response of the subject vehicle is due to the stimulus from all the vehicles surrounding the subject vehicle (multiple leaders, followers, and laterally adjacent vehicles). The "influence zone" of a subject vehicle is a assumed zone where the surrounding traffic environment influences the response of the subject vehicle. A rectangular shape of the surrounding vehicles influence zone with specific dimensions is used from the available literature [9]. Figure 1 depicts the vehicle's influence zone with surrounding vehicles. However, prior to lane changing maneuver, the subject vehicle when moving along with traffic stream has to maintain a safe or convenient longitudinal and lateral distance with the leading and adjacent vehicles. Following the objective of the study, the observations and findings of lateral clearance reported are pertaining to the subject vehicle and left side and/or right vehicles.

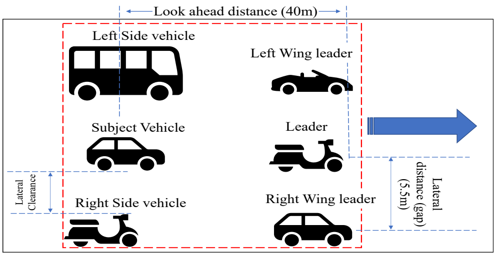

Fig. 1. Influence zone of subject vehicle and vehicles within the influence zone

3. Observations

3.1 Lateral Clearance

Lateral clearance between the vehicles after considering the width of vehicles is extracted using the trajectory data. The lateral clearance maintained or experienced by different vehicle classes with other vehicles on left or right is portrayed in Figure 2. The results in Figure are primarily for the vehicle classes in dominant proportions only, and the observations for LCV and Bus vehicle classes are merged for additional insights. From Figure 2 it can be observed that on average the vehicle classes of 2W and 3W exhibit lower lateral clearance values towards the left side vehicles compared to right side vehicles. Earlier study observed that the these two vehicle classes prefer kerbside lanes in general during their movements [3]. Hence, the tendency to shift towards kerb side lanes might be the reason for the observing lower lateral clearance values. For the vehicle class of Cars, the trend was found to be opposite, with lower lateral clearance values towards the right side vehicles compared to left side vehicles. Similar for 2W and 3W vehicle classes, the vehicle cars predominantly prefers median side lanes and tendency to shift towards right on the carriageway, even in the influence zone of the signalized intersection, resulting in lower lateral clearance with right side vehicles. The vehicle class of LCV and Bus were observed to occupy median side and intermediate lanes. However, following the trend based on lane preference and size of the vehicles, lateral clearance with right side smaller vehicle classes (2W & 3W) that are aiming to shift towards left side is less compared to smaller vehicles already on the left side. Accordingly, lateral clearance of LCV & Bus with vehicle class of Car and LCV-Bus (tendency to prefer right side lanes) is lower on the left side than on the right side.

It was expected that two particular vehicle classes (A&B) travelling abreast would yield towards similar lateral clearance values for left side (A-B) vs right side (B-A). In many cases it was even observed to be true. However, when observed on aggregate level for all the lateral vehicle interactions of particular vehicles, the results yielded different mean values and range, as detailed in next section.

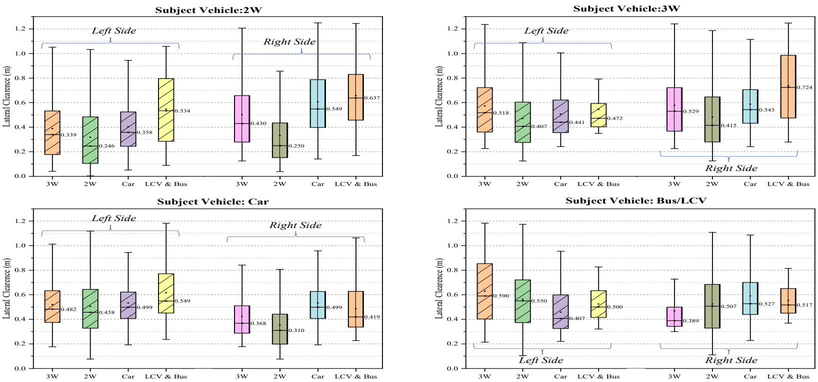

Fig. 2. Range of lateral clearance maintained between combination of subject and interacting vehicles on left and right side.

3.2 Descriptive Statistics

The descriptive statistics pertaining to the mean, standard deviation, minimum, and maximum value are detailed in **Table 1**. A single value is not always justifiable for traffic behavior analysis and assessment on microscopic level for weak lane disciplined traffic. Also, based on different combination of parameters and changes in vehicle, driver, environmental (operational) and traffic behavior (viz a viz also lateral clearance) also changes. Study and knowledge of the pattern of DBRP supplements for more robust traffic flow modelling [3]. Hence, the lateral clearance observed for different vehicle classes is studied for its probability distribution properties. Due to the advantages of the Generalized Extreme Value (GEV) distribution for traffic behavior parameters study, it is used in the present study [4]. GEV comprises distributions from three families, namely, Gumbel, Fréchet, and Weibull distributions, to describe the resulting data set. GEV distribution. And, the shape factor (k) of the distribution k= 0, k > 0, and k < 0 corresponds to the Gumbel, Fréchet, and Weibull distribution, respectively. However, the GEV might not always be the best fit. Still, to maintain consistency, the results of

GEV are detailed in Table 1. Two tests of Kolmogorov-Smirnov (KS) and Anderson-Darling (AD) are used to estimate the goodness of fit for the GEV distribution.

Table 1. Descriptive statistics for lateral clearance between different vehicles interacting on left and right side

SV-IV	Interacting side	Descriptive Statistics				KS test		AD test	ANOVA		
		Mean	Std. Dev.	Min.	Max.	Statistic	Critical value		F	F-crit.	*p-value*
2W-2W	Left side	0.317	0.247	0.007	1.033	0.055	0.059*	-	**2.233**	**3.84**	**0.14**
	Right Side	0.333	0.251	0.078	1.250	-	-	-			
2W-3W	Left side	0.388	0.243	0.061	1.051	0.064	0.101	0.918	25.67	3.85	0.00
	Right Side	0.501	0.283	0.135	1.247	0.031	0.043	2.188			
2W-Car	Left side	0.403	0.217	0.052	1.051	0.020	0.033	1.461	807.29	3.84	0.00
	Right Side	0.606	0.269	0.141	2.824	0.017	0.041	2.495			
3W - 2W	Left side	0.470	0.256	0.105	1.241	0.049	0.049*	3.080*	**0.79**	**3.85**	**0.37**
	Right Side	0.481	0.256	0.116	1.223	0.050	0.051*	-			
3W - 3W	Left side	0.573	0.254	0.226	1.236	0.068	0.150	1.030	**0.03**	**3.87**	**0.86**
	Right Side	0.578	0.243	0.226	1.241	0.063	0.101	0.868			
3W - Car	Left side	0.507	0.204	0.242	1.145	0.063	0.068	2.192	47.20	3.85	0.00
	Right Side	0.587	0.213	0.242	1.241	0.022	0.031	1.538			
Car - 2W	Left side	0.506	0.246	0.076	1.184	-	-	-	445.07	3.84	0.00
	Right Side	0.353	0.213	0.077	1.180	0.034	0.036	2.116			
Car - 3W	Left side	0.520	0.205	0.177	1.180	0.021	0.035	0.850	72.03	3.85	0.00
	Right Side	0.424	0.187	0.177	1.028	0.048	0.068	1.181			
Car - Car	Left side	0.629	0.262	0.214	1.183	0.109	0.135	1.468	14.31	3.91	0.00
	Right Side	0.467	0.196	0.301	0.994	0.138	0.194	1.095			

SV = Subject Vehicle; IV = Interacting Vehicle; K-S = Kolmogorov-Smirnov; A-D = Anderson-Darling. All results tested for $\alpha = 0.05$; (*) results significant at a confidence interval of 0.01 for Log-normal distribution; Anderson Darling test results are reported for critical value of 0.25008 @ $\alpha = 0.05$; (-) No robust Statistical distribution results are available.

Both the test being non-parametric in nature, the dependency on the prior assumption of the data is relaxed. Additionally, the absence of minimum data/sample points requirement for performing the tests adds to the benefit. In the KS test, KS statistics, denoted as 'Dstat' is calculated as the difference between the observed and predicted cumulative frequency distribution (CDF) curve. If the 'Dstat' value is less than the 'Dcrit' value, then the null hypothesis is accepted for the desired degree of level of significance. With null hypothesis is that the dataset follows the said distribution. All the combinations of the subject vehicle and interacting vehicles follow GEV distribution, with a p-value < 0.05 for 95% confidence interval. However, for a combination where the subject vehicle is interacting with the 2W vehicle class, no robust probabilistic pattern was observed. For a limited combinations that are observed to be statistically valid failed to follow GEV, and Log-normal distribution was observed to fit at 90% confidence interval. This highlights the complexity caused due to the presence of motorized 2W in the weak lane disciplined traffic. Their seepage/percolating nature, high maneuverability and lateral movements [2], [8], in addition with aggressive driving behavior [4] results in constantly changing interacting pairs and extreme observations in lateral clearance, making it difficult to observe any probabilistic pattern. In other words, it can also be interpreted that lateral clearance of a subject vehicle interacting with 2W is not entirely dependent on the driver's behavior and desire.

Also, to check the statistical relevance between lateral clearance observed between the subject vehicle and interacting vehicle of the same vehicle class on the left side and right side, the ANOVA test is performed at 95% confidence interval. Statements for ANOVA null hypothesis (H_0) denotes that lateral clearance values on left side and right side are equal. Subsequently, alternate hypothesis denoting them to be unequal. The results in the last column of Table 1, ANOVA ($F < F_{critical}$), concur that, for a combination of the same vehicle classes as the subject and interacting vehicle, there is no significant difference between the observed lateral clearance values for the left side or right side ($p>0.05$). with the exception of some combinations. Hence the null hypothesis may not be rejected and seems to be correct. Additionally, null hypothesis is also observed to be valid for the combination 3W-2W but invalid for the reverse combination of 2W-3W. All other combinations exhibit statistically significant lateral clearance values on left and right sides ($p<0.05$). Therefore, though similar values may be considered for lateral clearance on the left and right side for vehicle combinations between the same vehicle classes, it is imperative to note that the lateral clearance exhibited by vehicles of specific classes towards vehicles from different classes is statistically significant on the left side and right side.

3.3 Effect of speed on Lateral Clearance

Lateral clearance maintained by a subject vehicle at different operating speeds is often used to calibrate the lateral and lane-changing behavior in microsimulation. Often the minimum lateral clearance values are maintained by the vehicle at 0km/hr. and 50km/hr. (13.89 m/s) are needed [10]. Hence the plots for minimum lateral clearance observed at different speed levels corresponding to a different subject and interacting vehicle pairs are detailed in Figure 3.

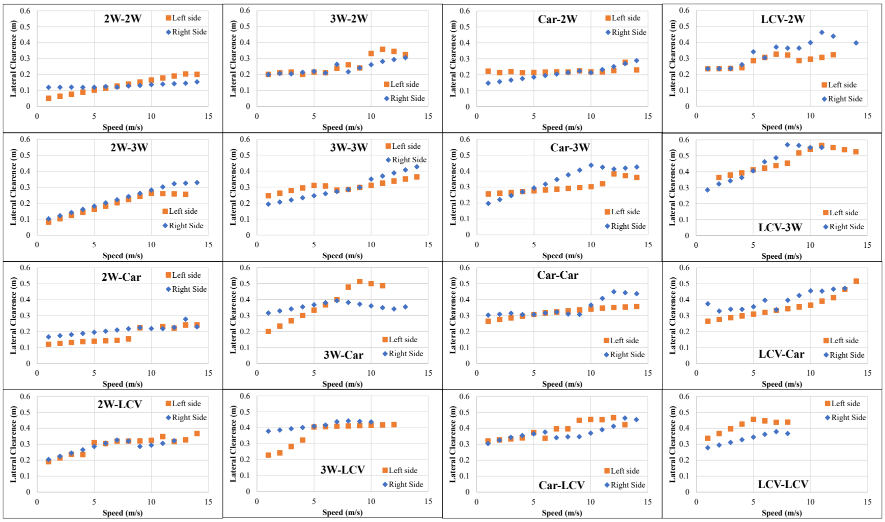

Fig. 3. Minimum Lateral clearance for combinations of Subject-interacting vehicle at different speeds

Studies report that the speed vs lateral clearance relation follows a upwards linear trend resulting in increasing lateral clearance with increasing speeds [7]. However, due to constrained in carriageway width, and congested/saturated conditions at signalized intersections, for many combinations of interacting vehicles, the lateral clearance is observed to be constant of remains almost similar after a certain speed value. This can also be inferred as, though a positive relationship is observed between the lateral clearance and speeds in the lower spectrum of the speed of the subject vehicle, after a certain threshold, the rate of increase in lateral clearance reduces and is observed to remain at a constant value. Hence a minimum safe clearance value for vehicles at high speeds can be reasonably assumed for modelling purposes

4. Summary

Mixed traffic and non-lane-based driving habits of drivers in developing countries like India pose a significant challenge to a precise analysis of traffic condition and behavior. The lack of detailed data further limits the depth to which the condition can be analyzed. Trajectory data forces its way through those limitations and provides a comprehensive insight into the traffic scenario. Longitudinal interactions of vehicles are thoroughly analyzed in the existing pool of literature. However, for weak lane disciplined mixed traffic conditions observed in India, the lateral driving behavior parameters are also pivotal in assessing and analyzing the traffic proper effective monitoring, management and operations. Studies have focused on lateral behavior of traffic in weak lane disciplined traffic, but the studies are limited to mid-block sections. It is evident from the literature that traffic behavior and safety aspects are significantly different at midblock and signalized intersections [3], [5]. Hence this study focused on exploring the lateral clearance i.e. the lateral safety spacing maintained by vehicles, observed at signalized intersections.

From the observations and inferences reported in the study, it is evident that the lateral clearance maintained by different vehicle classes while interacting with vehicle travelling abreast to the subject vehicle is statistically different. The lateral clearance maintained by vehicle classes on the left and right sides is also significantly different (Table 1). However, similar lateral clearance values can be considered for modelling for similar vehicle class combinations, but different values need to be considered for interactions between different vehicle classes. The results also show that the lateral clearance for left side and right side also varies for a subject vehicle according to the lane preference of the subject and/or interacting vehicle and their potential movement towards their desired lanes (lateral position on carriageway) (Figure 2). To avoid limitations due to a constant value of DBRP, the lateral clearance observed on the field is also checked for its statistical distribution fit. Based on the goodness of fit results from KS and AD test, GEV distribution can be reliably used for modelling the lateral clearance between almost all combinations of subject-interacting vehicle pairs, with special consideration and focus on 2W vehicle class as interacting vehicle due to high lateral movement, aggressive driving behavior at signalized intersections. Lastly, to aid in modelling or simulating the traffic conditions at the signalized intersection with weak lane disciplined traffic, minimum lateral clearance values observed at different speed limits are also identified and depicted in this study (Figure 3). Additionally, in case if optimization is to be performed for calibration of the traffic model (simulation), a single value may not yield appropriate results. Hence the range of lateral clearance for different vehicle pairs is also provided (Figure 2).

Several factors limit the applicability or accuracy of the existing vehicle traffic behavior models. This study aims to overcome these limitations. With the advent of autonomous driving vehicles and connected vehicles in many parts of the world, this technology is still a distance away from being implemented for mixed traffic non-lane based driving conditions. However, it is the aim of the authors that the values and facts provided in the study shall be helpful in exploring driving patterns and modification of the existing models and guidelines towards higher efficiency and safety standards. Studies highlight that when two vehicles travel parallel to each other, they tend to shy away (12), also the influence of other vehicles in the subject vehicle's influence zone on the lateral clearance remains to be assessed. These factors along with several others shall form the basis for future work with the addition of more data from different study locations.

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