

INFLUENCE OF TRAFFIC AND VEHICULAR CHARACTERISTICS ON LATER SHIFT OF VEHICLES UNDER VARYING ROADWAY AND GEOMETRIC CONDITIONS

Ramireddy Sushmitha^{1,*}, Jatoth Jithender², Anoop Raj³ and KVR Ravishankar³

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Abstract

The present study is carried out to analyze the lateral shift of different vehicle types while traversing on a horizontal curve with influence of geometrical elements and average speed of the traffic stream. Four different curves with varying radius of curvature and deflection angles were selected in Warangal city. Different vehicle categories were considered such as two-wheeler, car, and three-wheeler to analyze the lateral shifts in the field. The results of the study showed that two wheelers were more affected by the average speed of the traffic, whereas for cars, the overall width of the road at curve was found to be more significant. Difference of operating speed was found to be more significant for three wheelers. The present research found that the radius of curve, average speed of vehicles and overall width of road at curve were influencing the lateral shifts of vehicles irrespective of the vehicle type and hence these factors can be given more importance during the design of horizontal curve geometry.

Keywords: Vehicle Type; Average Speed; Curve Geometry; Horizontal curves; Lateral Shift; Mixed traffic condition

Introduction

A major contributor to the effectiveness and safety of road transportation at horizontal curves is the lateral shift of vehicles, which is defined as a vehicle diverting from its original trajectory. Numerous factors, such as road design, vehicle attributes, and traffic circumstances, might affect

this occurrence. Designing safer and more efficient transportation systems requires an understanding of how these factors combine to cause lateral shift. Traffic factors such as flow patterns, vehicle speed, and traffic density can greatly impact vehicle lateral behavior. For instance, a high traffic density can

¹ Civil Engineering Department, G. Pulla Reddy Engineering College (Autonomous), Kurnool, Andhra Pradesh, India-518007.

² Civil Engineering Department, Vignana Bharathi Institute of Technology (Autonomous), Aushapur, Ghatkesar, Hyderabad, Telangana, India-501301.

³ Civil Engineering Department, National Institute of Technology Warangal, Warangal, Telangana, India-506004.

* Corresponding author

make it more difficult for vehicles to maneuver, which increases the need for lateral shifts by drivers trying to get through crowded places. Similarly, differences in vehicle speed can result in disparate lateral movements, particularly in situations involving mixed traffic, where vehicles of various sizes and performance levels share the road. Vehicle attributes, including weight, size, and dynamic performance, are also very important in lateral shift. Particularly on roads with distinct geometric features, larger and heavier vehicles such as trucks and buses may experience different lateral dynamics than smaller passenger cars. The center of gravity of the vehicle, the characteristics of the tires, and the suspension system can all affect its lateral stability and, in turn, its propensity to move laterally. The complexity of lateral movements is further increased by geometric conditions and roadways. Vehicle movement laterally can be influenced by a number of factors, including surface conditions, road curvature, lane width, and grade. For example, lateral shifts may occur more frequently on narrow lanes or abrupt curves, particularly when combined with heavy traffic or unfavorable weather.

The purpose of this study is to investigate how these vehicular, traffic, and roadway elements affect vehicles' lateral shifts. Through an examination of these interactions under various geometric and roadway conditions, the research aims to offer valuable insights that can enhance road safety and guide the development of road infrastructure. The results may aid in the creation of policies and regulations that reduce lateral shifts and improve general traffic safety.

Literature_Review

The overview of the earlier research work related to effect of geometry on maneuverability and safety are presented in this section. A deterministic model was developed to predict collision rates at two-lane roadways, considering flow rate, mean speed, lane width, and shoulder width. Study results underscore the importance of geometric design factors in influencing collision rates (Garber and Ehrhart, 2000). The geometric design elements such as curve radius and super-elevation, are further explored in a research work, emphasizing their role in traffic safety and accident rates at horizontal curves (Yingxue, 2009; Aram, 2010). The turning maneuverability was analyzed for large vehicles, highlighting the effects of curve geometry on turning paths. The research study is relevant for understanding how different vehicle types interact with curve geometry (Cheng and Huang, 2011).

A research study used a hybrid manual-computer method to analyse curve parameters, noting that errors in curve length and radius measurements can impact predictions. This highlights the need for precise geometric data in safety analyses (Bogenreif *et al.*, 2012).

A mathematical model was introduced for assessing risk levels on expressways, incorporating factors such as observed speed and design speed. This model's reliability aligns with your study's focus on vehicle speed and its impact on lateral shift (Oh and Mun, 2012). Vehicle trajectory models were developed for curved sections, considering dynamic vehicle characteristics, which is crucial for understanding how vehicle trajectories affect lateral shifts (Yuan *et al.*, 2012). Accident modification functions related to curve radius, finding similarities across study areas were assessed (Elvik, 2013). This supports the relevance of geometric features in predicting accident rates, a theme echoed in (Jesna and Anjaneyulu, 2016), who conducted reliability analysis for horizontal curves in India.

A study explored how operating speed impacts crashes under mixed traffic conditions, which is pertinent for your study's focus on vehicle speed and its effect on lateral shift (Vayalamkuzhi and Amirthalingam, 2016). Research work investigated lateral vehicle placement on curves, noting a shift towards the centre with increasing curve radius, which directly relates to your interest in lateral shift (Das *et al.*, 2016). The research work examined geometric design factors and their influence on crash severity and speed distribution, respectively. Their findings reinforce the importance of geometric design in safety outcomes, which is central to your research on lateral shift (Haghighi *et al.*, 2018; Sil *et al.*, 2019).

The impact of geometric features such as superelevation and road markings on vehicle lateral shift were studied. Their results highlight the significance of these factors in lateral positioning, aligning with your investigation into how curve geometry affects lateral shift across different vehicle types (Yin *et al.*, 2020; Vyskocilova *et al.*, 2023). The study focused on accident-causing factors and turning movements at horizontal curves, providing foundational insights into how geometric design affects safety (Aram *et al.*, 2010; Cheng and Huang, 2011). Fitzsimmons *et al.* (2013); Hosseinpour *et al.* (2016) explored lateral positioning and crash impacts, further supporting the need for detailed geometric analysis.

In summary, while past studies have predominantly used simple regression models to correlate traffic, geometric, and crash data, This research aims to advance this by employing multi-level modeling and examining vehicle trajectories

and stability. This approach addresses gaps identified in the literature, such as the limited exploration of speed variation and vehicle stability in relation to curve radius and aims to provide a more nuanced understanding of how these factors influence lateral shift and overall safety at horizontal curves.

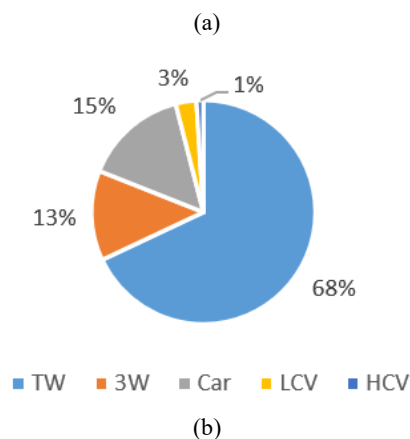
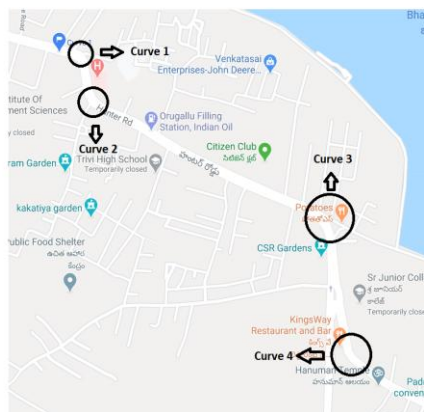


Figure 1. (a) Google Map Image (b) Percentages of Different Vehicle Categories at Study Locations

Field Data Collection and Extraction

Four different horizontal curves with varying geometry were selected on Hunter Road in Warangal city. The video graphic method was conducted during 7:00 AM to 11:00 AM and 3:00 PM to 7:00 PM on weekdays, to collect traffic, and vehicular data from the selected horizontal curve section. The video cameras were installed on high rise buildings from the appropriate vantage point to record the traffic operations. Traffic volume data was extracted by playing video files in LED

monitor in laboratory. The vehicles are categorized into five different types such as Two-Wheeler (2W), Three-Wheeler (3W), Car, Light Commercial Vehicles (LCV), and Heavy Commercial Vehicles (HCV). The classified volume count was made for every 5 minutes interval to identify the traffic composition. The google map image and traffic compositions of the chosen study sections shown in Figure 1.

Table 1. (a) Google Map Image (b) Percentages of Different Vehicle Categories at Study Locations

Curve	TW	3W	Car	LCV	HCV
Curve 1	688	127	155	30	13
Curve 2	695	127	163	29	12
Curve 3	702	132	173	28	14
Curve 4	609	123	121	24	11

The vehicular count of each vehicle types extracted from the videos at each section are presented in Table 1.

The geometric parameters such as lane width, inner paved shoulder, outer shoulder, extra widening, overall width before the curve and overall width at curve for all the sections were measured in the field. The geometric details of selected horizontal curve sections are shown Table 2.

Table 2. Geometric details of selected horizontal curve sections

Parameters	Length (meters)			
	Curve 1	Curve 2	Curve 3	Curve 4
Lane width	7.00	7.00	7.00	7.00
Paved shoulder inner	0.35	0.35	1.60	0.35
Outer shoulder	2.30	1.60	0.35	1.10
Extra widening on curve	0.60	0.20	0.20	0.05
Overall width before curve	9.65	8.95	8.95	8.45
Overall width at curve	10.25	9.15	9.15	8.25

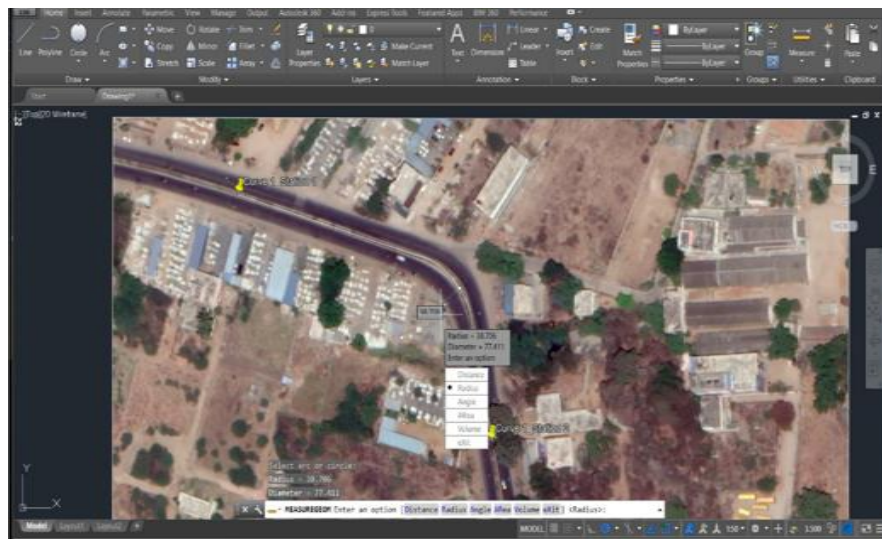
The other geometric parameters such as deflection angles and radius of curvature of selected horizontal curves were extracted using google earth and Civil 3D software. The google earth images of the study horizontal curves were imported to Civil 3D software and are adjusted to suitable scale. Adjustment of scale can be done by locating the points with pins and noting down the coordinate points. These points can be transferred to Civil 3D

and hence the scale of the image gets automatically fixed. The curves are drawn over the imported image and the best fit curve is drawn by trial-and-error method. After the best fit curve is drawn in Civil 3D, the Radius of the curve can be measured by direct line measurement. Deflection angle is found out by drawing the forward and backward tangent and then measuring the angle formed between them. Both these measurements can be easily found out by the MEASURE command available in the software. Figures 2(a) and 2(b) represents the procedure for importing google earth image and measuring deflection angle.

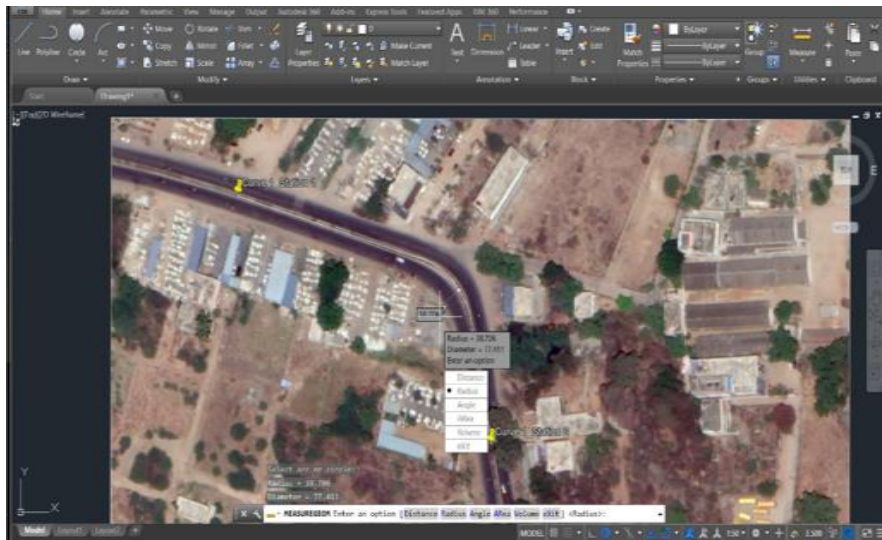
The extracted data such as Radius of Curvature, Deflection Angles and Length of Curves of selected sections are given in Table 3.

Table 3. Radius, deflection angle and radius of curve

Curve	Radius of curve (m)	Deflection angle (degrees)	Length of the curve (m)
Curve 1	38.71	62.37	42.13
Curve 2	75.66	57.49	75.91
Curve 3	126.52	70.17	154.95
Curve 4	45.94	39.68	31.81



(a)



(b)

Figure 2. (a) Exporting the google earth image (b) deflection angles measurement in Civil 3D software

Table 4. Mean and Standard deviation of speed for different vehicle types at study locations

Vehicle Type	Curve 1		Curve 2		Curve 3	
	Mean Speed (Kmph)	Standard deviation (Kmph)	Mean speed (Kmph)	Standard deviation (Kmph)	Mean speed (Kmph)	Standard deviation (Kmph)
TW	28.67	4.4	32.05	5.2	36.06	6.4
3W	24.74	2.2	27.42	2.6	32.92	3.6
Car	31.59	6.4	34.11	6.8	38.46	7.2

Table 5. Speed characteristics for study curves

Speed (Kmph)	Curve 1					
	Before curve			On curve		
	TW	3W	Car	TW	3W	Car
98 th percentile speed	44.00	38.62	43.18	34.00	31.00	35.06
85 th percentile speed	37.75	35.00	37.85	29.00	29.00	32.00
50 th percentile speed	30.00	31.00	32.00	25.00	24.00	28.00
15 th percentile speed	27.00	28.00	28.15	21.00	22.00	25.00
Speed (Kmph)	Curve 2					
	Before curve			On curve		
	TW	3W	Car	TW	3W	Car
98 th percentile speed	49.00	44.00	52.80	44.00	39.70	44.80
85 th percentile speed	43.00	38.00	48.00	37.20	35.00	40.00
50 th percentile speed	35.10	32.00	41.00	34.10	25.00	34.10
15 th percentile speed	27.70	27.00	28.40	29.00	22.95	29.00
Speed (Kmph)	Curve 3					
	Before curve			On curve		
	TW	3W	Car	TW	3W	Car
98 th percentile speed	50.40	44.74	49.74	47.00	42.90	48.04
85 th percentile speed	45.00	42.05	46.55	43.00	40.15	46.00
50 th percentile speed	37.00	33.50	40.00	37.00	33.00	39.00
15 th percentile speed	32.00	29.45	36.00	32.00	28.00	33.65
Speed (Kmph)	Curve 4					
	Before curve			On curve		
	TW	3W	Car	TW	3W	Car
98 th percentile speed	41.68	38.62	47.14	41.00	33.00	41.09
85 th percentile speed	39.00	35.50	39.05	36.00	32.00	35.15
50 th percentile speed	34.00	32.00	32.00	32.00	28.00	30.50
15 th percentile speed	30.00	29.00	27.00	28.85	22.25	24.85

The spot speed values of different vehicle types were collected using Radar gun. The collected speed data of various vehicle types were analysed, the mean speed and standard deviation of different vehicle types are given in Table 4.

These spot speed values were collected at two different locations for each curve. One location at the beginning of the curve and another one at point of maximum curvature which helped to analyse the speed characteristics and speed change behaviour of vehicles which are negotiating the horizontal curves. The 98th Percentile Speed, Operating Speed, 50th Percentile Speed, and 15th Percentile Speed of the traffic stream before the curve and on the curve were analysed for all the study locations. The speed characteristics vehicle types, before the curve and on the curve at section are given in the Table 5.

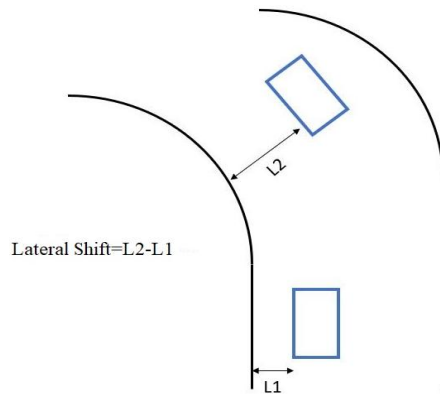
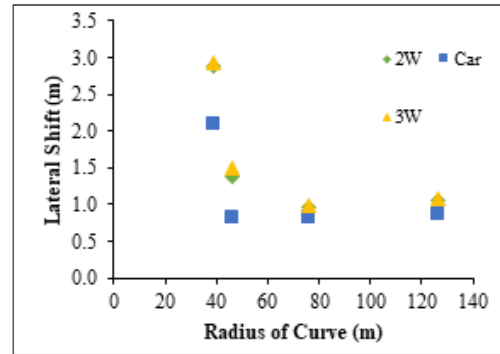
To collect the lateral shift data of vehicles white strips were drawn on the road 0.5m apart at two locations. One location was at the entry of the

curve and another one was on the point of maximum curvature. This was done to analyse the lateral shift of each vehicle negotiating the horizontal curve. The distance of the outer wheels of the vehicles from the median were noted from these two locations and then subtracted. The difference between these two distances gave the lateral shift of the vehicles. The measurement of lateral shift in the field at horizontal curves is represented in Figure 3.

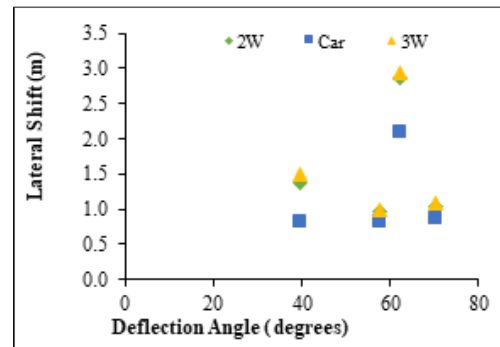
For minimizing error and developing a better model, 100 sets of each vehicle type at each location of curve were analysed. Each 100 sets were subdivided into sets of 20 vehicles for computing the average lateral shift and average speed. Table 6 shows the average lateral shift for different vehicle types for each curve.

Table 6. Speed characteristics for study curves

Vehicle type	Lateral shift (meters)		
	TW	3W	Car
Curve 1	2.88	2.93	2.09
Curve 2	0.96	0.98	0.83
Curve 3	1.05	1.09	0.88
Curve 4	1.38	1.49	0.81

**Figure 3. Measurement of lateral shift from field**

(a)

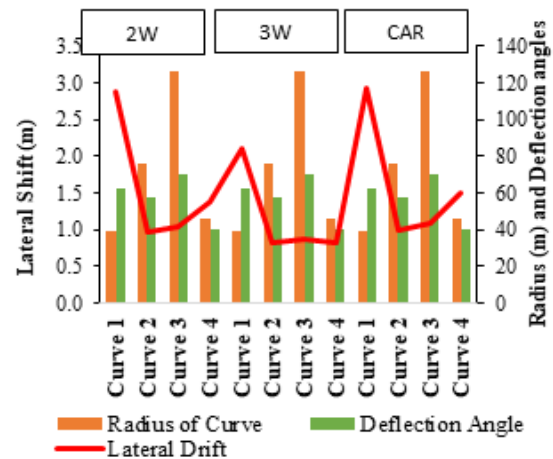


(b)

Data Analysis and Results

The lateral shift of vehicles tends to increase when the radius of the curve increases. The sharp increase of shift is found predominantly when the radius of curve is less than 60 m. And observed that beyond 80m of radius, the lateral shift value stabilizes between the range of 0.5 m to 1 m. Increase in deflection angle make it difficult for the vehicles to stay in their original path of travel. But deflection angle alone does not make a huge impact on Lateral Shift. The effect of deflection angle on Lateral shift is highly dependent on the radius of curvature too. It can be observed that the Two wheelers and Three Wheelers gets easily affected by deflection angle whereas Cars have better ability to manoeuvre the curves and have less lateral shift. The variation of lateral shift with radius curvature and deflection angle is shown in Figure 4.

The combination of both the radius of curve and deflection angle has an impact in the deviation of paths of different vehicles. From the data collected it can be noted that the maximum shift of vehicles, which is more than 2 m happens when the Radius of Curve is less than 50 m and Deflection angle is greater than 50 degrees. Influence of Radius of Curve and Deflection Angle on Lateral Shift is shown in the Figure 5.

Figure 4. Variation of Lateral Shift with (A) Radius of Curvature, and (B) Deflection Angle**Figure 5. Influence of Radius of Curve and Deflection Angle on Lateral Shift**

The variation of lateral shift with the length of the curves and overall width of road were analysed. It is observed that the lateral shift of 2Ws and 3Ws were high when the length of the curve was less. Cars showed less lateral shift even at lower length of curve since the deflection angle was too less in that curve showing that cars can easily manoeuvre the curves with lower deflection angles even though the radius of curve was less. The lateral shift was more for roads having higher overall width pertaining to the fact that more widths allowed vehicle drivers to take up more space for turning their vehicles on the curve. The variation analysis of lateral shift with length of the curves and overall width of road is shown Figure 6.

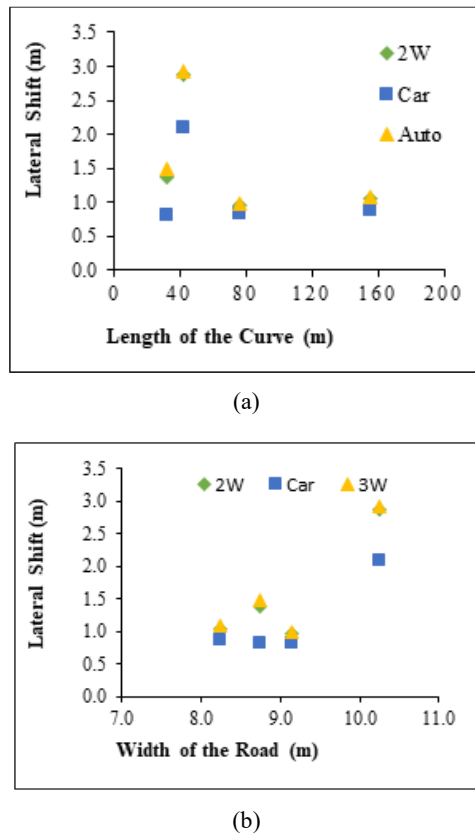


Figure 6. Variation of Lateral shift with (a) Length of the curve and (b) Overall width of the road at curve

The lateral shifts were found to be more when the average and operating speeds of the vehicle on the curve location were less. It can also be noted that when the difference of speeds was more, the Lateral shifts also found to be increasing. This shows that vehicles which tend to decrease their speeds at a higher rate found to more difficult to manoeuvres

the curve and ended up having more lateral shift compared to vehicles which did not have such a variation in speeds while curve traversing. Relationship between Lateral shift with Operating Speed and Average Speed shown in Figure 7.

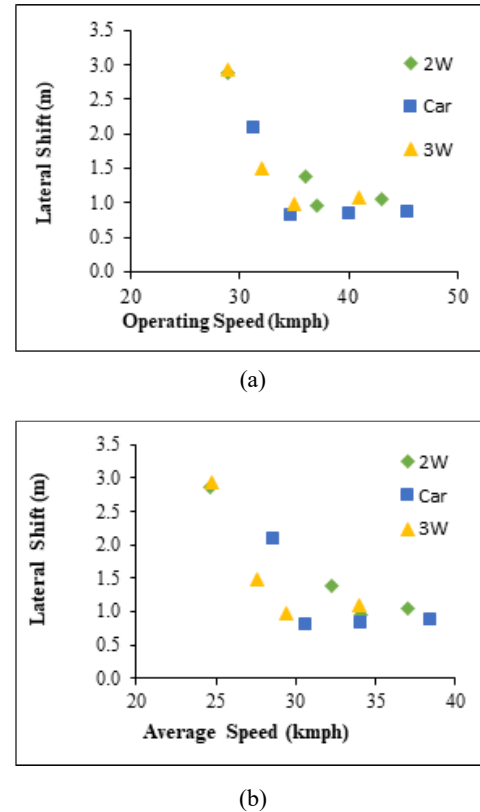


Figure 7. Relationship between Lateral shift with (a) Operating Speed and (b) Average Speed

Modelling of Lateral Shift

For modelling, correlation matrices were analysed for different vehicle types separately. The variables such as the average lateral shift, radius of curvature, deflection angle, length of curve, overall width of road at curve and average speed during a particular period when the average lateral shift was considered for analysis of correlation matrix. The correlation matrix for lateral shift analysis for two-wheeler vehicle type is given in Table 7.

From the correlation matrix in Table 7, the lateral shift of two wheelers is having strong correlation with Average speed on the curve, compared to other factors. The correlation matrix for lateral shift analysis for Car vehicle type is given in Table 8.

Table 7. Correlation Matrix for Analyzing Lateral Shift of Two Wheelers

	Lateral Shift	Radius of Curve	Deflection Angle	Length of the curve	Overall Width of the road at curve	Difference in Operating Speeds	Average Speed on the Curve
Lateral Shift	1						
Radius of Curve	-0.45	1					
Deflection Angle	0.09	0.12	1				
Length of the curve	-0.41	0.74	0.35	1			
Overall Width of the road at curve	0.47	-0.32	0.45	-0.54	1		
Difference in Operating Speeds	0.38	-0.24	0.68	-0.74	0.43	1	
Average Speed on the Curve	-0.96	0.21	0.01	0.17	-0.02	-0.14	1

Table 8. Correlation Matrix for analysing Lateral Shift of Cars

	Lateral Shift	Radius of Curve	Deflection Angle	Length of the curve	Overall Width of the road at curve	Difference in Operating Speeds	Average Speed on the Curve
Lateral Shift	1						
Radius of Curve	-0.42	1					
Deflection Angle	0.29	0.62	1				
Length of the curve	-0.37	0.94	0.45	1			
Overall Width of the road at curve	0.89	-0.14	0.03	-0.21	1		
Difference in Operating Speeds	0.24	-0.41	-0.27	-0.53	0.66	1	
Average Speed on the Curve	-0.45	0.19	0.54	0.85	-0.80	-0.54	1

Table 9. Correlation Matrix for Analysing Lateral Shift of Three-Wheelers

	Lateral Shift	Radius of Curve	Deflection Angle	Length of the curve	Overall Width of the road at curve	Difference in Operating Speeds	Average Speed on the Curve
Lateral Shift	1						
Radius of Curve	-0.27	1					
Deflection Angle	0.06	0.63	1				
Length of the curve	-0.44	0.24	0.15	1			
Overall Width of the road at curve	0.39	-0.14	0.03	-0.21	1		
Difference in Operating Speeds	0.95	-0.27	-0.12	-0.33	0.16	1	
Average Speed on the Curve	-0.35	0.21	0.32	0.15	-0.30	-0.14	1

Table 10. Lateral Shift Models for Different Vehicle Types

Vehicle Type	Lateral Shift Model	R ² value	P-value
Two-Wheeler	Lateral Shift= $6.542-(0.154 \times \text{Average Speed on Curve})$	0.863	0.001
Car	Lateral Shift= $-4.533+(0.629 \times \text{Overall Width of Road at Curve})$	0.743	0.003
Three-Wheeler	Lateral Shift= $-125+(0.493 \times \text{Difference in Operating Speeds})$	0.892	0.000

Table 11. The validation table showing error and RMSE value for models 1, 2 and 3

Vehicle type	Model	Observed lateral shift (m)	Predicted lateral shift (m)	Error (%)	RMSE
Two wheeler	1	1.38	1.58	14.27	0.20
Car	2	0.81	0.97	19.72	0.16
Three Wheeler	3	1.48	1.60	8.14	0.12

From the correlation matrix in Table 8, the lateral shift of cars is having strong correlation with Overall width of the road at curve, compared to other factors. The correlation matrix for lateral shift analysis for Three-wheeler vehicle type is given in Table 9.

From the correlation matrix in Table 9, the lateral shift of Three-wheelers is having strong correlation with Difference in Operating Speeds, compared to other factors. The lateral shift modelling was done for the different vehicle types by considering significant factors affecting on it. Based on the correlation and the regression analysis, the lateral shift models of various vehicle types are given in Table 10.

Validation of Lateral Shift Models

The Models 1, 2, and 3 are checked for validation, 70% of data was used for model development and remaining 30% data used for validation. Table 11 shows the predicted value for average lateral shift and compares it with the observed average Lateral Shift. The error values of all the three models are less than 20% and RMSE value is less than 5, (recommended by Srikanth *et al.* 2017; Srikanth and Mehar, 2017) hence the model is validated.

The model 1 is applicable only for speeds greater than 20 kmph and maximum speeds of 50 kmph as the radar gun did not read speeds below 15 kmph and the lower and upper limits of the speeds under study were 20 kmph and 50 kmph respectively. The model 2 is valid only for four lane divided roads and model 3 is applicable to three wheelers traversing in the horizontal curves having radius values between 40m and 120m.

Conclusion

The effect of geometrical features and speed characteristics on the lateral shift of vehicles were tried to analyse in this study. Traffic and geometric data were collected from four curves and the relationship between the variables were analysed. The influence of radius of curvature, deflection angle, average speed, length of curve, overall width of road on the average lateral shift of vehicles were studied. The variation of lateral shift with different significant variables were considered and modelled.

‘The Average Speed on Curve’ is found to be the most influencing factor for evaluating lateral shift of two wheelers. The lateral shift is observed to be 1.38 m for two wheelers on horizontal curves. ‘The overall width of the road at curves’ is found to be the most influencing factor for finding lateral shift of cars, and the lateral shift is found to be 0.81 m for cars on horizontal curves. ‘Difference in operating speed’ is significantly affecting lateral shift of three wheelers and is found to be 1.48 m for three wheelers on horizontal curves. It is concluded from the present study that the different vehicle types have different nature of curve manoeuvres and different values of lateral shift. This lateral shift can be considered in safety and design aspects. Also, this can be used as a variable when accident modelling is done and can also be checked when the radius of curve, width of roads at curves and speed limits are fixed.

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