Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Evaluation of Speed and Lateral Position for Inter-Vehicle Interaction

Gourab Sil[a]*, Suresh Nama[b], Avijit Maji[c], Akhilesh Kumar Maurya[d]

[a,c]*Indian Institute of Technology Bombay, Powai, Mumbai: 400076, India*
[b,d] *Indian Institute of Technology Guwahati, Guwahati, Assam 781039, India*

Abstract

Generally the horizontal curve design is evaluated for geometric influence. Researchers had used free flowing vehicles for this purpose and evaluated the effect of geometry on driver behaviour (e.g., speed, lateral position). Any possible inter-vehicle interaction in the curve section prior to the centre may influence the speed and lateral position. In this research all the possible inter-vehicle interactions were identified and analysed for the influence. Evaluation of speed profile and lateral position distribution confirmed the influence of inter-vehicle interactions. Therefore, for the horizontal curve geometry evaluation, the present research recommends only the vehicles which are completely uninfluenced till the curve centre. Moreover, the study reveals that in general drivers are likely to choose inside lane for curve negotiation and it is prominent for sharper curves. This behaviour need further research to understand the effect on the safety and geometry evaluation of horizontal curves.

Keywords: Speed; Lateral position; Horizontal curve; Free flow; Geometry evaluation

1. Introduction

Drivers drive based on their perception of the roadway ahead. Generally, highway geometry and vehicles within vicinity influence the perception. While approaching a horizontal curve, the drivers chose vehicle speed and lateral position 50 to 100m upstream section of point of curvature (PC). This upstream section is known as curve discovery section because here the drivers first discover the horizontal curve (Campbell et al. 2012). Researchers opined that driver starts adjusting speed just before or at the starting of the curve and can continue till curve centre (Hashim et al., 2016; Sil et al. 2018b). In the absence of other vehicles, subject vehicle's speed is actually the driver's preferred speed.

The evaluation of horizontal curve design considers driver behaviour at the curve centre (Lamm et al. 1995;

* Corresponding author. Tel.: +91-9038152961
E-mail address: silgourab@gmail.com

Gibreel et al. 1999; Krammes et al. 1995). In this evaluation vehicle is only influenced by the geometry and not by any vehicle within the vicinity of the curve discovery point to the curve centre (Campbell et al. 2008, Sil et al. 2018a,b,c). Researchers consider free flow (FF) criteria to satisfy this requisite (Jacob and Anjaneyulu, 2013; Misaghi and Hassan, 2005; McFadden and Elefteriadou, 2000). Generally, a threshold headway is used as free flow (FF) criteria at curve centre. However, in four-lane divided highway the free flow evaluation only at curve centre cannot guarantee the free flow (e.g., maintaining a 100m space headway or 5 sec time headway) throughout curve manoeuvring section. This is because the inter-vehicle interaction can happen prior to the centre and remain unobserved due to the spot observation (Sil et al. 2018a; Sil and Maji 2017a).

Earlier researchers have used free flow criteria only at the curve centre to study driver behaviour (Jacob and Anjaneyulu, 2013; Sil et al. 2018d; Fitzpatrick et al. 2000; Sil and Maji 2017b, c; Maji et al. 2018). However, the effect of inter-vehicle interaction (prior to the curve centre) on the driver behaviour was unexplored and unknown. Such interaction may or may not affect the driver behaviour. This warrants driver behaviour study for inter-vehicle interaction from the curve discovery point to the curve centre (CC). The speed and lateral position were commonly used by the researchers to evaluate diver behaviour for horizontal curve geometry. Moreover, these parameters can be directly obtained from field measurement. Therefore, the objective of this research is to evaluate the effect of inter-vehicle interaction on a) Driver speed choice and b) Lateral position.

2. Literature Review

Researchers (Zwahlen and Schnell 1999; Campbell et al. 2008) asserts that the drivers start perceiving the curve at 75m to 100m upstream of the beginning of the curve (i.e., the curve discovery segment). However, the exact position is not well defined and could be closer to the beginning of curve to enable more visibility. Moreover, available literatures suggest a reaction time approximately 2sec for safe driving (Zwahlen & Schnell 999; AASTHO 2011; Krammes et al. 1995; Fitzpatrick et al. 2000; Campbell et al. 2012). Hence, a distance 50m prior to the beginning of a curve, which equates to a reaction time of approximately 2 sec for a vehicle traveling at 100 kmph, is reasonable. Researchers also found that drivers wait to initiate speed adjustment until they are close to the curve (Hashim et al., 2016; Glennon et al., 1985). It reflects their expectancies to choose an appropriate speed based on their perception of curve geometry.

To evaluate geometric design, various geometric consistency evaluation techniques were adopted by many European countries and Australia (Gibreel, 1999). Geometric consistency evaluation requires speed profile along the horizontal curve alignment (Gibreel, 1999). The speed profile can be developed by tracking the free flowing vehicles along the curve (Misaghi and Hassan, 2005; McFadden and Elefteriadou, 2000). Therefore, tacking of free flow vehicle is important in geometric design and safety evaluation.

Researchers had collected spot data using video recording and trap length method (Boora and Ghosh, 2016; Fitzsimmons et al., 2012; Dey et al., 2006; Jacob and Anjaneyulu, 2012; Sil et al., 2018, Nama et al. 2016). They have used different trap lengths varying between 10m and 60m to estimate spot speed. Further, Sil and Maji (2017a) suggested 15m trap length for nominal error in speed measurement. Vehicles having headway equal to or greater than certain threshold headway is considered to be free flowing vehicles. In some earlier studies, researchers have considered 5 sec headway for free-flow condition and used it in spot-speed data collection (Jacob and Anjaneyulu, 2013; Hashim et al., 2016; Gong and Stamatiadis, 2008; Poe et al., 1996; Russo et al., 2015, 2016). Dey et al. (2006) collected lateral position data by dividing the lane width into 25 cm sections. These sections were marked with self-adhesive cloth tape. The position of the rear left wheel of a vehicle crossing any section was recorded as lateral position of that vehicle. Using the data they studied the lateral position distribution of mixed traffic on two-lane roads. Similar method was adopted by Mohapatra and Dey (2015) to evaluate lateral position behaviour of U-turning vehicles.

Horizontal curve with radius up to 500m are considered as sharp, (Figueroa and Tarko 2005; Jacob and Anjaneyulu 2013) which may affect the driver’s choice of speed and lateral position. Curvature (1/Radius) is the main influencing parameter (Lamm 1995; Krammes 1995; Fitzpatrick 2000). To evaluate the effect of curvature only radius or the combined effect of curve length and deflection angle can be considered (Fildes and Triggs 1985). Effect of gradient up to 5% is negligible (Sil et al. 2018a, Russo et al. 2016) for passenger car speed choice.

3. Site Selection and Data Collection

The scope of this study was restricted to four-lane divided highways only. In total four horizontal curves with radius varying 90m to 360 m were chosen for data collection on national highway 3 (NH-3) connecting Thane to Nasik, India. The highway geometric data of the sites were obtained from National Highways Authority of India (NHAI) and Mumbai Nasik Expressway Limited (MNEL) in the form of plan and profile drawings. The obtained information was cross-checked at the site using surveying equipment. The geometric details of sites are presented in Table 1. All the sites have similar carriageway width (7m) on either side, shoulder width (3m) on the far side of the cross section, superelevation (2.5%), gradient (up to 2%) and the surface layer is of asphaltic concrete. All the sites were selected only on rolling terrain. The survey was planned to conduct during daytime and in dry pavement conditions. Moreover, these sites were chosen carefully to satisfy the following conditions.

i) Avoid presence of intersections or median openings and road side interference to eliminate the unwanted influence.
ii) Presence of uniform lane markings and guardrail,
iii) Adequate sight distance
iv) Low average daily traffic (ADT) and
v) Availability of vantage points for installing video cameras

Table 1: Site details

Site no.	Radius in m
1	90
2	165
3	280
4	360

Before designing speed and lateral position data collection, it was essential to plan the vehicle tracking process for all the possible inter-vehicle interactions before the curve centre. The data collection and extraction methodology proposed by Sil and Maji (2017a) and Sil et al. (2018a) was adopted for the vehicle tracking. This method suggests video based data collection technique and was adopted in this research. In total three locations 1) 50 m before the point of curvature (PC_{50}), 2) point of curvature (PC) and 3) curve centre (CC) along the curve were considered as tracking stations (Figure 1).

The vehicle was considered as influenced when it fails to satisfy the threshold headway criteria (w.r.t same or adjacent lane vehicle ahead) at a specified location before the centre. This happens when the vehicle overtook or overtaken before reaching the centre. In this research, we considered 5sec headway as free flow criteria. In total four cases of inter-vehicle interaction can be observed for which free flow (i.e., ≥ 5 sec.) criteria get satisfied at CC. These cases are as follows:

i) Not influenced (NI) at all the three locations (NI-NI-NI).
ii) Influenced (I) at first location (I-NI-NI)
iii) Influenced (I) at second location (NI-I-NI)
iv) Influenced (I) at both first and second location (I-I-NI)

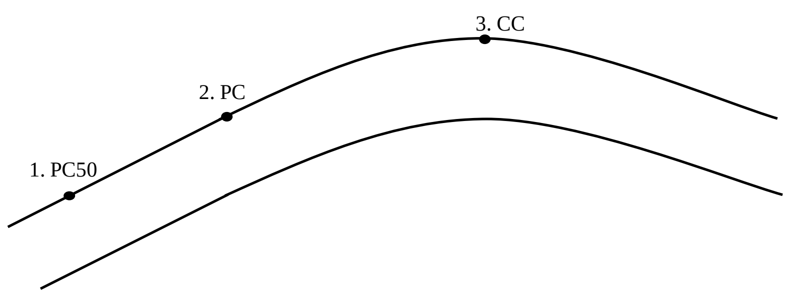

Figure 1: Schematic diagram of the vehicle tracking along the horizontal curve

In this study speed and lateral position of the passenger cars (PC) were collected and extracted. The speed data were obtained using the travel time to cross the 15m trap marked on the pavement (Figure 2). For further details see Sil and

Maji. (2017a). Whereas, for the lateral position data the entire carriageway was divided and marked into sections of 25cm each at the middle of the trap and across the road as presented in Figure 2. During data extraction, the front left wheel crossing the marked section was recorded as lateral position. All data were extracted manually using the video editing software in the laboratory.

Figure 2: Typical image of the sites

4. Analysis

The extracted speed and lateral position data was analysed for the possible influence of vehicle interaction on free flow speed in all the four cases considered in this study. ASSHTO (2011) defines the observed speed of majority of motorists (i.e. 85th percentile speed, V_{85}) as driver's speed choice. Hence, the 85th percentile (V_{85}) of the speed data at three location were estimated separately for all the four cases.

4.1 Effect on speed

The 85th percentile speed (V_{85}) profiles for all the inter-vehicle interaction cases were plotted along the three locations (i.e. PC_{50}, PC and CC) of the four horizontal curves and presented in Figure 3. These plots evaluate the effects of inter-vehicle interaction on speed choice profile. It is clear that the drivers maintain the speed in all the three points along the curve when it is not influenced at all three locations (i.e. for NI-NI-NI case). This trend is consistent in all the sites and can be referred as preferred speed for the radius of the site. In all the sites, the speed drops in second location (i.e. PC) for the case NI-I-NI. It confirms the influence of inter-vehicle interaction at second location (i.e., the threshold headway criteria was violated when the tracked vehicle was monitored for the free flow evaluation). However, it seems that immediately after this effect the drivers accelerate and choose the preferred speed at the curve centre (i.e. CC) in all the three sites except the site 4. However, approximately the 2kmph lower speed than the preferred speed at the curve centre (CC) of site 4 is not significant and can be considered as same. Similarly, when there is any inter-vehicle interaction at first location (PC_{50}) i.e. the I-NI-NI case, the speed choice is meets the preferred speed at the curve centre (CC) for 90m radius curve. Whereas, for higher radius it immediately reaches to the preferred speed at second location (PC). This difference may be attributed to the defensive driving nature on the sharper curve. That indicate drivers are more cautious after inter-vehicle interaction on 90m curve and accelerates gradually. In other words, they select a lower speed very early before reaching the first location (PC_{50}) for defensive driving along 90m curve and accelerates gradually after the influence of other vehicle. Otherwise, if there is no influence they might accelerate abruptly to reach the preferred speed at 2nd location (PC), as in other cases. Similar observation for the I-I-NI case support this finding. It can be noted that for the I-I-NI case in 90m curve, the drivers are unable to reach the preferred speed at the curve centre (CC). Whereas, for the other higher radius curves they achieve it. The dissimilar trend for 90 m curve may be attributed to the early and more speed drop for defensive driving behaviour on sharper curve. It also can be observed that for this case in site 2 and site 3 (radius 165m and 280m) drivers maintain a speed at first (PC_{50}) and second location (PC) and then accelerates to the preferred speed at the curve centre (CC). This is the anticipated trend for this case. However, in site 4 (R=360m) the higher speed choice at first location (PC_{50}) in spite of the influence may be due to other reason and need further investigation. As the location 1 (PC_{50}) is on the tangent and the forthcoming curve have different radius, that combination might influence the speed choice and warrants further research.

In conclusion, the speed profile plots of all the four sites confirm the influence of inter-vehicle interaction on speed choice before the curve centre. Though the speed choice is almost similar at curve centre (CC) for all the four cases, the findings indicate there is an additional speed adjustment workload imposed on the drivers due to the vehicular interaction before the curve centre. Hence, such vehicle should not be considered for geometric design or safety evaluation of horizontal curves.

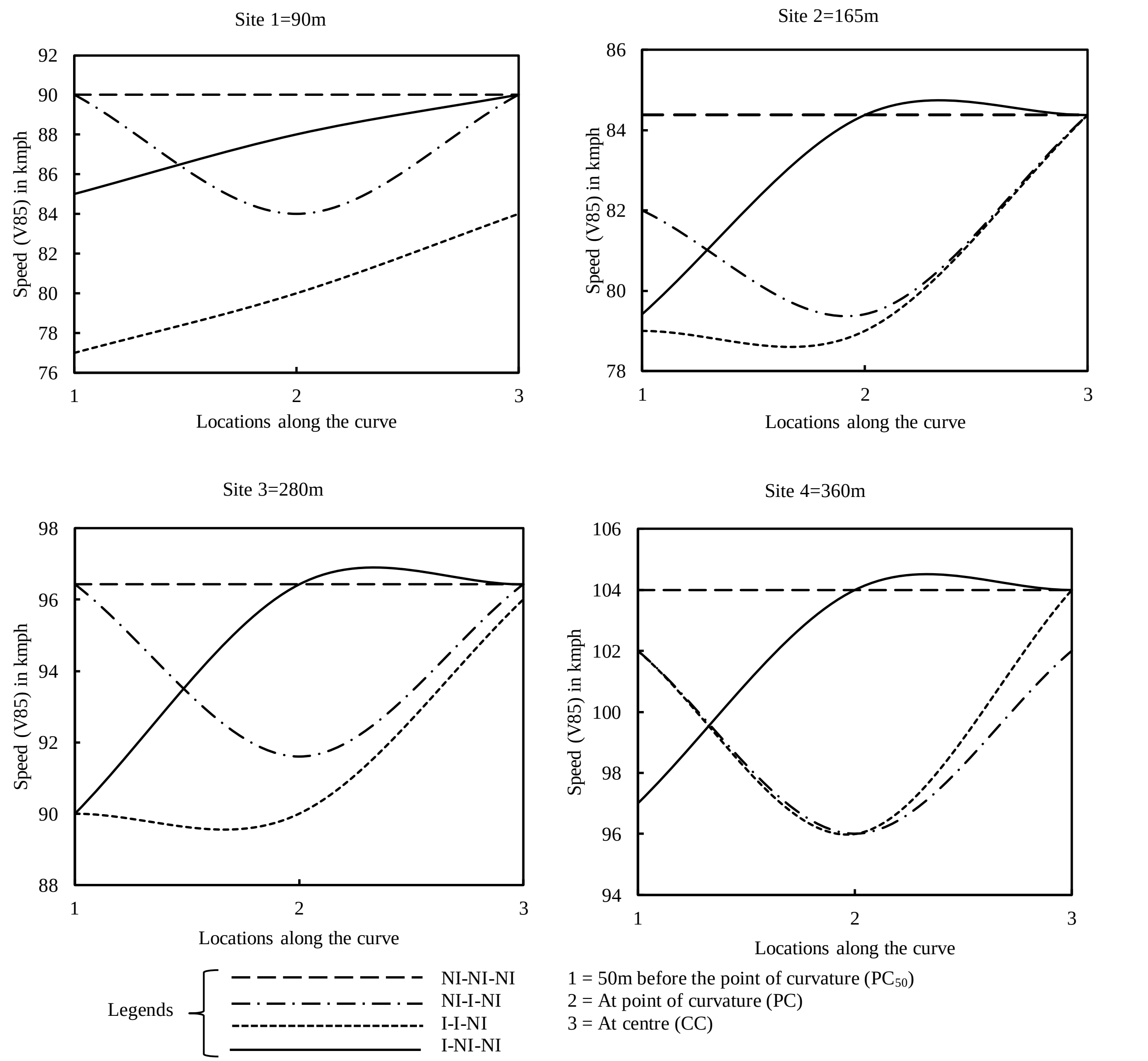

Figure 3: Speed profile along the horizontal curve

4.2 Effect on lateral position (LP)

The lateral position was selected as another measure in this research. The lateral position only at the curve centre was considered as another indicator of influence for the inter-vehicle interaction. The Figures (4-7) presents the frequency distribution of all the four cases for site 1 to site 4, respectively. The abscissa designates the lateral position from outside edge line marking of the curve. Whereas, ordinate represents the frequency of vehicles observed on the corresponding lateral position with the accuracy of 25cm. For 90m radius, the lateral position is almost concentrated between 200cm to 550cm and have the peak between 400cm to 500cm for all the cases. This may be attributed to the sharper radius. For smaller radius, the lateral position is shifting towards to the inside lane. For the NI-NI-NI case, clear two peaks are observed in case of sites 2 to 4. Also, the vehicles were used a wide carriageway compare to other cases. In all the sites, most of the cases have one peak other than the NI-NI-NI case. Further, in sites 2 and 4, NI-I-NI case has two peaks, but in these sites, the vehicles are widely distributed for the case NI-NI-NI. The lane wise percentage share of vehicles lateral position is presented in Table 2. It is observed that the lateral position is shifting towards the inside lane, when the vehicle is affected early before the centre. Higher percentage of inside lane and high negative skewness in case of I-I-NI and I-NI-NI confirms this fact. In case of NI-NI-NI and NI-I-NI, comparatively more share (%) of lateral position on outside lane, less negative skewness and observation from Figure (4-7) indicates drivers are comparatively more likely to use both the lanes. Furthermore, the drivers are more likely to choose inside lane in 90m radius curve. This may be due to the effect of larger curvature. This indicates the influence of inter-vehicle interaction is minimal for a significant effect of the curvature.

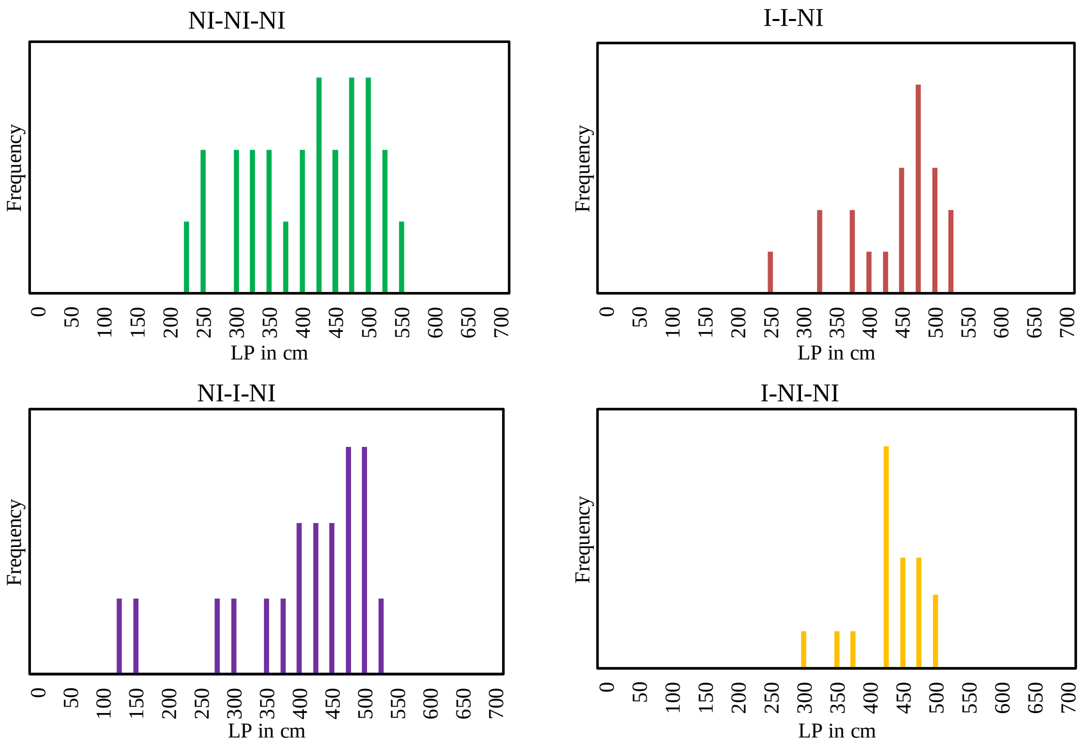

Figure 4: Lateral position for site 1(R=90 m)

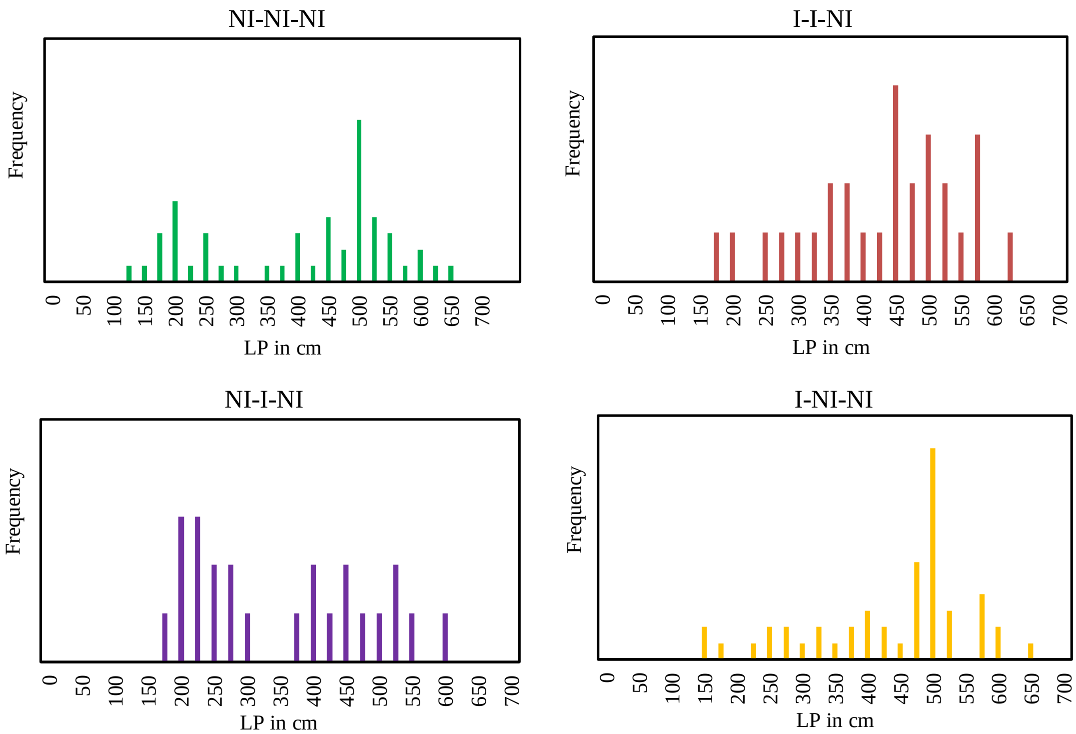

Figure 5: Lateral position for site 2 (R=165 m)

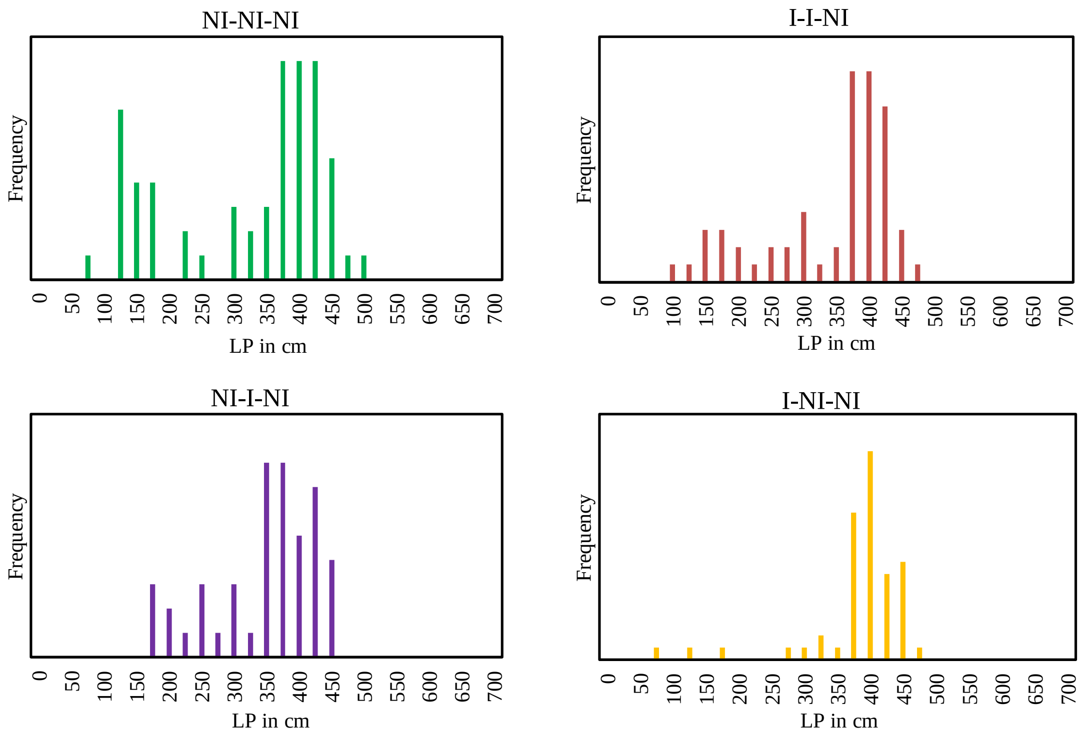

Figure 6: Lateral position for site 3 (R=280 m)

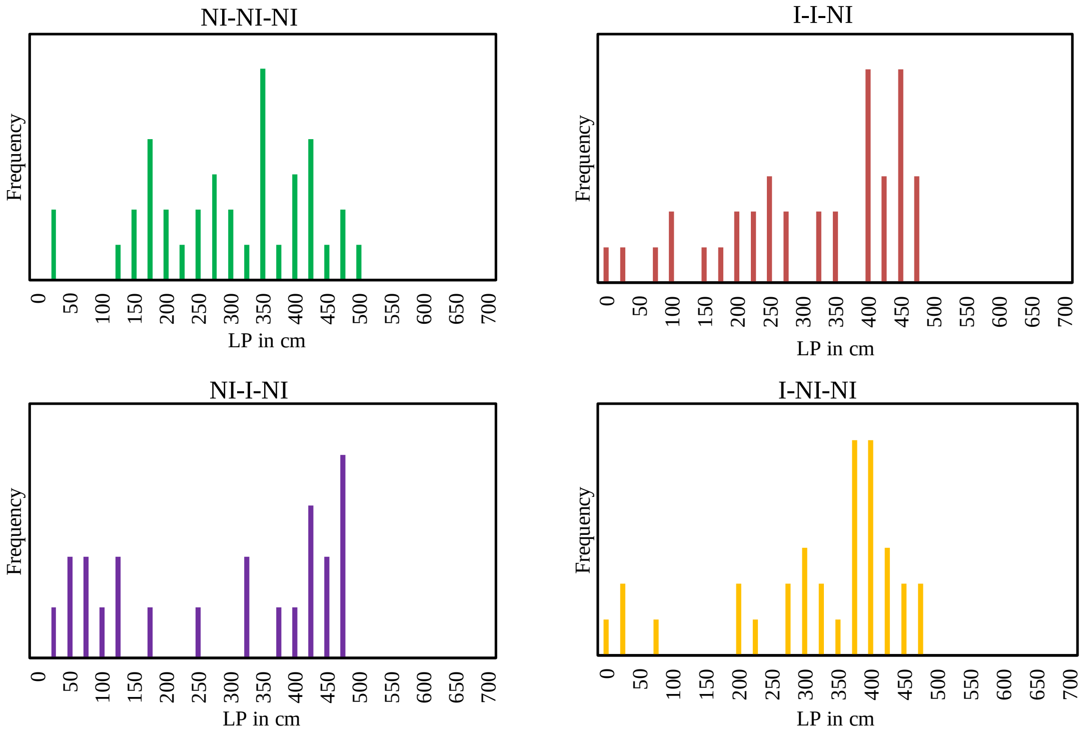

Figure 7: Lateral position for site 4 (R=360 m)

Table 2: Lane-wise percentage share of the vehicles

Site No.	NI-NI-NI			I-I-NI			NI-I-NI			I-NI-NI		
	OL %	IL %	γ	OL %	IL %	γ	OL %	IL %	γ	OL %	IL %	γ
1	12	88	-0.38	5	95	-1.10	16	84	-1.33	0	100	-1.10
2	28	72	-0.43	11	89	-0.49	38	62	0.28	12	88	-0.79
3	31	69	-0.64	22	78	-1.01	20	80	-0.82	6	94	-2.54
4	37	63	-0.41	36	64	-1.32	44	56	0.48	21	79	0.70

Where; OL=Outside lane, IL=Inside lane and γ= Skewness

5.0 Conclusion

In this research vehicle speed and lateral position was studied for the possible influence of inter-vehicle interaction before the curve centre. The speed and lateral position data on four different horizontal curves in four-lane divided highway were collected. Further, the data were separately extracted for the four possible vehicle interaction and utilized in analysis. The extracted speeds were used to develop 85^{th} percentile speed profiles along the horizontal curves. The lateral position data were used to plot frequency distribution at curve centre. It was observed that vehicle maintains a uniform speed when not influenced anywhere till the curve centre (NI-NI-NI case). Unlikely, in other three interaction cases influence of inter-vehicle interaction was observed. This indicates there are additional speed adjustment work load imposed on the drivers due to the vehicular interaction before the curve centre. Hence, such vehicle should not be considered in geometric design or safety evaluation of horizontal curves.

While the vehicles are influenced early to the curve centre, they are likely to choose the inside lane. Hence, the influence encouraging the divers to choose the inside lane and indices a defensive driving for the inter-vehicle interaction. Generally, the drivers prefer the inside lane and it is prominent for the sharpest curve (R=90m). However, this behaviour needs further research to understand the effect on safety and geometry evaluation of horizontal curves.

The comparative observation of the influence on speed profile and lateral position for overall uninfluenced case (NI-NI-NI) versus other three influenced cases indicates a clear difference. Therefore, in the horizontal curve geometry evaluation the NI-NI-NI case is recommended for free flow data collection.

Acknowledgements

Authors would like to thank Ms. Divya Shanu for her support in data extraction. Authors are also thankful to National Highways Authority of India (NHAI) for providing the plan and profile, and Mumbai Nasik Expressway Limited (MNEL) for providing support in field data collection. Further, authors are grateful to the Indian Institute of Technology Bombay, India for providing financial assistance to conduct the study.

References

American Association of State Highway Transportation Officials (AASHTO). 2011. "A

Boora, A. and Ghosh, I., 2016. Identification of free flow condition on two-lane intercity highways under heterogeneous traffic condition, 27th ARRB Conference, Linking people, places and opportunities, Melbourne, Australia.

Campbell, J.L., C.M. Richard, and J. Graham. NCHRP Report 600B: Human Factors Guidelines for Roadway Systems. HRB, National Research Council, Washington, D.C., 2008.

Dey, P. P., Chandra, S. and Gangopadhaya, S. 2006a. Lateral distribution of mixed traffic on two-lane roads. Journal of Transportation Engineering. ASCE, 132(7), pp. 597–600.

Figueroa, M. A. and Tarko, A. 2005. Speed factors on two-lane rural highways in free-flow conditions, Transportation Research Record: Journal of the Transportation Research Board 1912: 39-46

Fildes, B. N., & Triggs, T. J. (1985). The on effect of changes in curve geometry magnitude estimates of road-like perspective curvature. Perception & psychophysics, 37(3), 218-224.

Fitzpatrick, K., Wooldridge, M. D., Tsimhoni, O., Collins, J. M., Green, P., Bauer, K. M., Parma, K. D., Koppa, R., Harwood, D. W. Anderson, I., Krammes, R. A., and Poggioli, B. (2000). Alternative Design Consistency Rating Methods for Two-Lane Rural Highways. Final Report. (Report FHWA-RD-99-172). McLean, VA: FHWA.

Fitzsimmons, E.J., Souleyrette, R.R. and Nambisan, S.S., 2012. Measuring Horizontal Curve Vehicle Trajectories and Speed Profiles: Pneumatic Road Tube and Video Methods, Journal of Transportation Engineering, 139(3), 255-265.

Gibreel, G. M., Easa, S. M., Hassan, Y., & El-Dimeery, I. A. (1999). State of the art of highway geometric design consistency. Journal of transportation engineering, 125(4), 305-313.

Glennon, J.C., T.R. Neuman, and J.E. Leisch. Safety and Operational Considerations for Design of Rural Highway Curves. FHWA/RD-86/035. Federal Highway Administration, U.S. Department of Transportation. 1985.

Hashim, I. H.; Abdel-Wahed, T. A.; Moustafa, Y. 2016. Toward an operating speed profile model for rural two-lane roads in Egypt, Journal of traffic and transportation engineering (English edition) 3(1): 82–88.

Jacob, A., and Anjaneyulu, M. V. L. R., 2012. Operating speed of different classes of vehicles at horizontal curves on two-lane rural highways, Journal of Transportation Engineering, 139(3), 287-294.

Krammes, R. A., Brackett, Q., Shafer, M. A., Ottesen, J. L., Anderson, I. B., Fink, K. L., Collins, K. M., Pendleton, O. J. and Messer, C. J. (1995). Horizontal Alignment Design Consistency for Rural Two-Lane Highways. FHWA-RD-94-034, FHWA, U.S. Department of Transportation, Washington, DC.

Lamm, R., Guenther, A. K., and Choueiri, E. M. (1995). ''Safety module for highway geometric design.'' Transp. Res. Rec. 1512, Transportation Research Board, Washington, D.C., 7–15.

Maji, A., G. Sil, and A. Tyagi. (2018). "The 85th and 98th Percentile Speed Prediction Models of Car, Light and Heavy Commercial Vehicles for Four-Lane Divided Rural Highways." Journal of Transportation Engineering, Part A: Systems 144(5). Advance online publication. doi: 10.1061/JTEPBS.0000136.

McFadden, J., and Elefteriadou, L. (2000). Evaluating horizontal alignment design consistency of two-lane rural highways: Development of new procedure, Transportation Research Record, 1737, Transportation Research Board, Washington, D.C., 9–17.

Mohapatra, S. S., & Dey, P. P. (2015). Lateral placement of U-turns at median openings on six-lane divided urban roads. Transportation Letters, 7(5), 252-263.

Nama, S., Sil, G., Maurya, A. K., & Maji, A. (2016). Speed Prediction Models of Four-Lane Horizontal Curves for Indian Driving Behavior. In Proceedings of Transportation Planning and Implementation Methodologies for Developing Countries, Mumbai, India.

Poe, C.M., Tarris, J.P. and Mason, Jr. JM. 1996. Relationship of operating speed to roadway geometric design speed. FHWA-RD- 96-024, FHWA, U.S. Department of Transportation, Washington, D. C.
Policy on Geometric Design of Highways and Streets." Washington D.C.

Russo, F.; Biancardo, S. A.; Busiello, M. 2016. Operating speed as a key factor in studying the driver behaviour in a rural context, Transport 31(2): 260–270.

Russo, F.; Fric, S.; Biancardo, S. A.; Gavran, D. 2015. Driver Speed Behavior on Circular Curves of Undivided Two-Lane Rural Roads: Serbian and Italian Case Studies, Transportation Research Record: Journal of the Transportation Research Board 2472:117–128.

Sil, G., A. Maji, S. Nama, and A.K. Maurya. (2018a). "Operating Speed Prediction Model as a Tool for Consistency Based Geometric Design of Four-Lane Divided Highways." Transport 33: 2018.

Sil, G., and A. Maji. (2017a). "Video Based Data Collection Process for Geometric Design Consistency Evaluation of Four-Lane Median Divided Horizontal Curves." Transportation Research Procedia 27: 672-679.

Sil, G., and A. Maji. (2017b). "Development of Speed Prediction Model for Curve in Mixed Traffic Conditions." Paper presented at International Conference on Advances in Highway Engineering and Transportation Systems (ICAHETS-2017), 21-22 Jul 2017, Negombo, Sri Lanka.

Sil, G., Maji, A., Nama, S. and Maurya, A.K. (2018b). Operating Speed Prediction Model as a Tool for Consistency Based Geometric Design of Four-Lane Divided Highways. Transport.

Sil, G., S. Nama, A. Maji, and A.K. Maurya. (2018c). "The 85th Percentile Speed Prediction Model for Four-Lane Divided Highways in Ideal Free Flow Condition." Extended abstract presented at the 97th Annual Meeting of the Transportation Research Board: Washington, D.C. (No. 18-02808).

Sil, G., S. Nama, A. Maji, and A.K. Maurya. (2018d). Effect of Horizontal Curve Geometry on Vehicle Speed Distribution: A Four- Lane Divided Highway Study. In Proceedings of Recent Advances in Traffic Engineering, Surat, India.

Sil, G., Nama, S., Maji, A. and Maurya, A.K. (2017c). "Modelling of Operating Speeds for Multilane Divided Highways", 4th Conference of Transportation Research Group of India (CTRG), Mumbai, India.

Zwahlen, H., & Schnell, T. (1999). Driver-headlamp dimensions, driver characteristics, and vehicle and environmental factors in retroreflective target visibility calculations. Transportation Research Record: Journal of the Transportation Research Board, (1692), 106-118.