SPEED ESTIMATION MODEL OF VEHICLE AT HORIZONTAL CURVES ON TWO-LANE HIGHWAY

Ankit H. Patel, Milan P. Kacha, Pinakin Patel, Dr. L.B. Zala

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Birla Vishvakarma Mahavidyalaya Engineering College, Gujarat, Indiaankit.patel.ap802@gmail.com

Abstract

In this study, 85^{th} and 98^{th} percentile speed estimation models of vehicle on two-lane rural highways were developed using a statistical technique of multiple regression. Models were developed using spot speed data obtained from five sites out of total eight and data of three remaining sites were taken into account for validation. Speed of vehicle at 50m initial to point of curvature, point of curvature, middle of the curve along with Geometric aspects of Horizontal curve and section adjacent to tangent were considered as independent variables. Car and SUVs speed for the 85th and 98th percentile was found to be parallel, so united for further analysis. Vehicle speed at middle of the curvature was found to be dependent on its speed at previous segment and geometric features predicted previously. Speed estimation of car and two-wheeler at middle of the curve was found to be strongly corelated with curve length and deflection angle. Gradient at particular locations was resulted to be a most affecting parameter for 85^{th} percentile speed of HCV and LCV. The 98th percentile speed at middle of the curve were found in strong correlation with speed at 85th percentile speed. Root mean square errors were calculated to be within range of 2 to 8 km/h. study concluded that length of curve could be a very significant factor in the practice of highway geometric design.

Keywords: Speed estimation model, Horizontal curve geometry, Highway geometric design consistency, Two-lane highway

I. Introduction

Road accidents are mainly caused by factors associated to one or a mixture of the three elements of the traffic system: the road, the driver and the vehicle. Among these, Driver error is quoted as main contributor to road accidents (04). Driver accident and errors are further expected to occur due to inequality between what drivers may have conviction in to be a safe speed and real time speed with which a feature can be passed securely (08). Abrupt changes in roadway characteristics surprise drivers, resulting in speed errors or critical driving maneuvers that lead to collisions.

At most the promising strategies to improve traffic safety on rural highways is the implementation of the concept of design consistency. Design consistency is known as the conformance of highway geometric design with driver anticipation (07). highway geometric design consistency defined as the mark to which highway systems are designed and developed to sidestep collision risk with critical driving manoeuvres. A consistent design harmonizes driver performance by reducing speed variations (01). It also reduces speed differences between different classes of vehicles.

Most widely used approach in the area of design consistency Among the different approaches to design consistency evaluation is an operating speed-based approach (04). The first step in this approach is the development of models for predicting operating speed.

Numerous models have been developed to predict operating speed on horizontal curves in different parts of the world. However, there is large variation in model form, explanatory variables, and regression coefficients. This might be due to the changes in driver behaviour and road geometrics (07). This highlights the fact that no single model is universally acceptable. So far, no study has been reported on the design consistency of two-lane rural highways in India.

The commonly seen vehicles on rural highways in India are cars, motorized two-wheelers, buses, and trucks. The static characteristics, such as length, width, and height, dynamic characteristics, such as acceleration rate, engine power, and load carried, vary widely among these vehicles. These variations, coupled with driver behaviour, result in considerable differences in the speed of different classes of vehicles.

Literature considered passenger car and rarely heavy commercial vehicle in the majority of speed estimation model development. Only a few studies measured an effect of two-wheeler, SUVs and bus which plays significant role to Indian mix traffic condition.

A reliable operating speed model could be a useful tool in the evaluation of alternate designs and in the selection of the right design choice for the improvement of roads. Operating speed models will be useful for establishing speed limits for highway sections of unfavourable design.

A. Vehicle Classification Consideration

The Indian Automobile Manufacturers classified passenger cars in eight segments based on engine capacity and vehicle length. However, the most widely used passenger cars in India have engine capacity less than 1,500 mL and length less than 4 m. Therefore, passenger cars meeting these two criteria were considered in this study. Other than passenger cars, sports utility vehicles, light commercial vehicles, and heavy vehicles were considered in this study. The technical details of these vehicle categories are:

- Passenger cars: Passenger vehicles with total length less than 4m, engine capacity less than 1,500 cm^3 and ground clearance less than 170 mm;
- Sport utility vehicle: Passenger vehicles with total length greater than 4 m, engine capacity greater than 1,500 cm^3 and ground clearance above 170 mm;
- Light commercial vehicle: Commercial vehicles with gross vehicle weight less than metric 7.5 t; and
- Heavy commercial vehicles: Commercial vehicles with gross vehicle weight greater than 7.5 t.

II. LITERATURE REVIEW

Previous studies considered effect of geometry on speed of vehicle at two lane rural highways. These studies resulted that speed of vehicle is largely affected by radius of curve (02). Length of curve, change in the ratio of curvature and vehicle speed at the beginning of a curve is found to be impacted on operating speed at middle of the curve (MC). However, operating speed of vehicle were not disturbed by radius of curvature above 450m, and it is similar to speed of vehicle at tangent section 800m (07). previously researcher have tried to develop a speed prediction model inputting above geometric parameters as explanatory variable Moreover, ordinary least square modeling methods were taken into account (04). Though, routine of supplementary methods such as panel data modeling and artificial neural network (ANN) are not infrequent what's more (06). explanatory variables techniques and Relevant modeling adopted in vehicle operating speed estimation modeling are summarized further. Excluding a scarce, all the available operating speed estimation models were for two-lane undivided highways (01). four lane highway models were developed by developed for operating speed estimation. Nevertheless, Semeida and Morris and Donnell multilane highways speed models were developed (03).

Most of the operating speed estimation models were for passenger cars and a few were available for light and heavy commercial vehicles such as trucks. Further, the choice of speed data collection devices depended on factors such as ease of installation, data collection duration, and details required. It is evident that existing studies vary widely (05). The independent variables studied, models developed, vehicle types adopted, and data collection setup considered were different in those studies. It indicated that studies were highly context sensitive and outcomes were geographic region specific. Hence, more studies on various vehicle types for four-lane divided highways are required for better design of highways.

III. SITE SELECTION

It is a Two-lane divided rural highway with a provision of grade-separated intersections. Sites satisfying the criteria given subsequently were selected for the study. These sites meet the geometric design standards of IRC: SP-73 (IRC 1983). The highway geometric data of the study sites will be obtained with the help of Google earth and AutoCAD Civil3D. It was observed from data that these sites had no variations in superelevation rate, carriageway width, and shoulder width. Site consideration is strictly as per the following steps:

- Horizontal curves had radius 450 m or less;
- Sites were free from influence due to intersections or median openings;
- No pedestrian activity, work zones, narrow bridges in the vicinity of the site;
- Embankment of 3m or more were protected by traffic barrier such as guardrail;
- Pavements were marked for at least 3.5 m wide lanes and in good condition;
- Presence of paved shoulder of at least 1.5 m width in good condition;
- Presence of transition curves before and after the horizontal curve.

Vasad- Dakor state highway (SH-183) located in state of Gujarat is fulfilling above all criteria so it was selected as study area. Eight selected horizontal curve locations are shown in fig.1

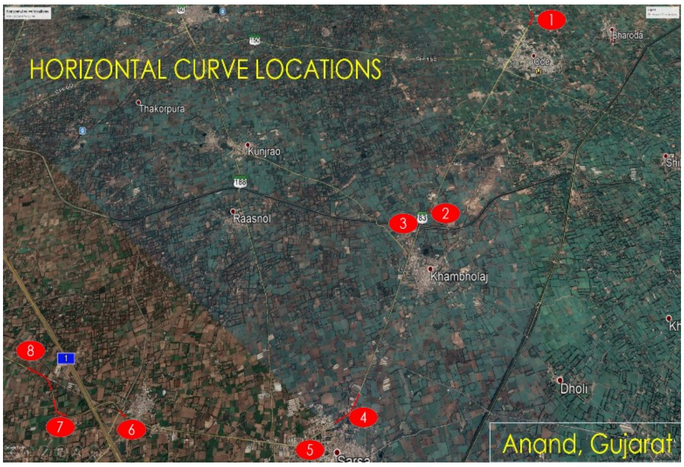


Figure 6 Horizontal curve locations

IV. DATA COLLECTION

The collected data have two main components: geometric data and speed data. The database contains the details of 15 horizontal circular curves and their preceding tangent sections. Among them eight critical sites were selected based on data made available from highway designing software AutoCAD Civil3D. The selected sites satisfied the following requirements:

- Two-lane two-way undivided at least 100m away from Intersection,

Table 7 Descriptive Statistics of Geometric Parameters for Selected Sites

Statics	Radius	Speed	Length Of Curve	Deflection Angle	Tangent Length	G_{PC50}	G_{PC}	G_{MC}	G_{PT}	G_{PT50}
MIN	60	30	20.316	8.111	55	-4.1	-1.55	-0.9	-1.5	0
MAX	345	60	157.063	26.084	80	0.3	1.5	3.6	0.9	2.6
MEAN	181.875	48.75	53.975	15.629	65.75	-0.79	0.244	0.47	-0.17	0.537
SD	88.557	12.464	51.886	9.714	18.077	1.509	0.875	1.45	0.953	0.889

- Tangent length equal to or greater than 50m,
- Grade of road between +4 and −4%, and
- Away from the vicinity of intersections.

Vehicles can decelerate well before entering the horizontal curve (Jacob and Anjaneyulu 2013; Poe et al. 1998). Therefore, speed of the vehicle is determined with data collected at five locations of each curve; 50 m initial to point of curvature (PC50), point of curvature (PC), middle of the curve (MC), See Fig. 2 for the speed data collection setup. Traps of 15 m length will be noticeable on the pavement at these locations. The speed of vehicle at PC50 specifies the speed on tangent section, at PC the speed while incoming a curvature, at MC the speed that driver understand suitable to maneuver a

Figure 7 Data extraction Using software

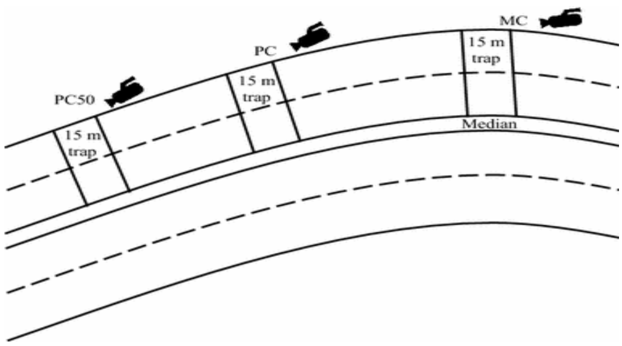


Figure 3 Data collection setup

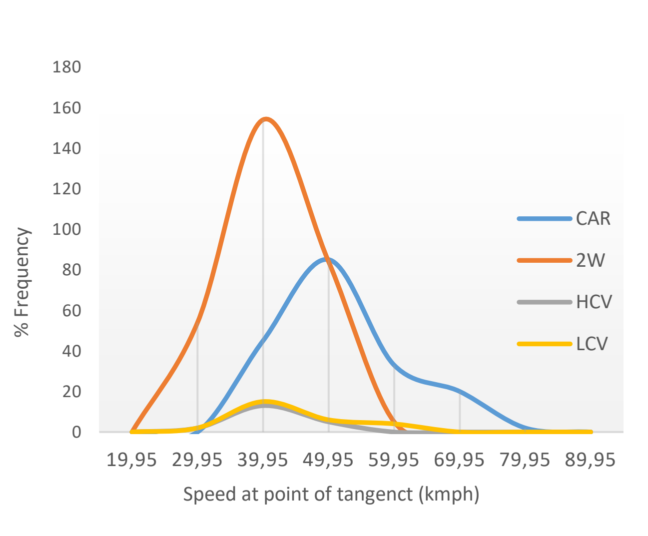
Video cameras will be installed at vantage points and will be inconspicuous to drivers for data collection. The video logs will be recorded between Jan 2020 and Mar 2020 for approximately 3 hrs. a day with good weather and adequate daylight only.

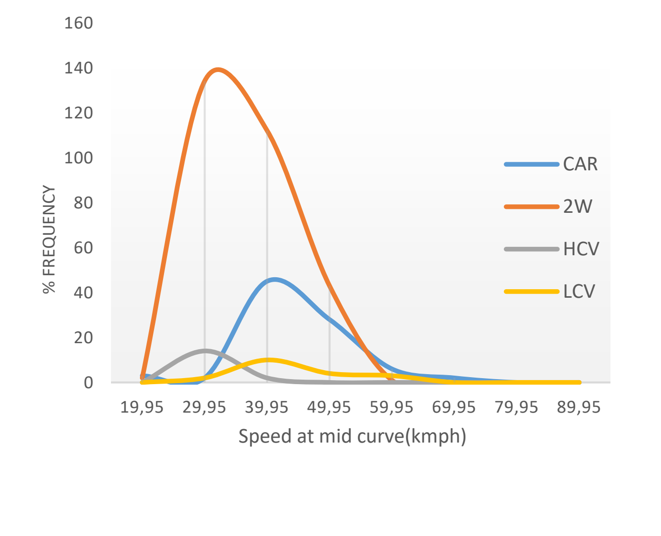
However, to ensure accuracy and minimize error in the video logs, the following precautions will be adopted:

- The camera view will not block by signboards, roadside plantations, etc.
- Cameras will be installed at a height of 2.1m on tripods for clear visibility of the trap lines
- Cameras will be located close to the trap lines to minimize parallax error but ensured to remain unobtrusive to the Tripods. will be protected firmly on the ground to avoid trouble from vibration and wind gust due to high-speed traffic movements.

V. DATA ANALYSIS

The spot speed data obtained with the help of avidmux software of data extraction and then analysis in excel. Later, Normality of data will be checked using Jarque Bera test. The normal distribution curve for mean data of operating speed model obtained is shown in following graph. From the frequency distribution curve, it can be stated that Car and 2W data has the maximum frequency and wide variation of speeds as compare to HCV and LCV data which can be stated firmly from following graph shown in Fig.4. Speed at point of tangency having a higher median speed compared for same vehicle at mid curve which was previously stated in Jacob and Anjaneyulu MVLR (2013).





VI. Speed Estimation Models

The sites used did not demonstrate variations in lane width, shoulder, width, shoulder type, and superelevation. However, geometric design parameters such as radius, deflection angle, curve length, preceding tangent length, and vertical gradients and traffic parameters such as vehicle speed and vehicle type. study the independent variables considered were horizontal curve radius, curvature, length of curve, deflection angle, preceding tangent length, and vertical gradient at 50 m prior to the point of curvature (GPC50), point of curvature (GPC), midcurve (GMC).

A stepwise multiple linear regression method was used in developing the intended speed estimation models. The obtained models are shown in Eqs. (1) – (16). In these equations, speed is expressed in km/h and the predictor variables in SI units. All models were obtained at 95% confidence limit and the predictor variables in the obtained models are significant at 95% confidence level (i.e., p-value ≤ 0.05).

A. 85th percentile speed estimation model

1) Model for MID CURVE

1. $V_{85CAR\text{-}MC} = 37.898 - 0.204L_C + 0.471\Delta + 230.45/R$ Adjusted $R^2 = 0.63$
2. $V_{85TW\text{-}MC} = 40.022 - 0.015L_C - 0.158T_L - 311.224/R$ Adjusted $R^2 = 0.56$
3. $V_{85HCV\text{-}MC} = 37.228 + 0.048L_C + 0.369\Delta - 3.79G_{MC}$ Adjusted $R^2 = 0.34$
4. $V_{85LCV\text{-}MC} = 42.392 + 0.048L_C + 1.22G_{MC} - 1.45G_{PC}$ Adjusted $R^2 = 0.426$

2) Model for PC

5. $V_{85CAR\text{-}PC} = 47.244 - 0.079L_C + 1.03\Delta$ Adjusted $R^2 = 0.99$
6. $V_{85TW\text{-}PC} = 46.61 - 0.076L_C + 0.526T_L$ Adjusted $R^2 = 0.614$
7. $V_{85HCV\text{-}PC} = 36.051 - 0.056L_C - 3.236G_{PC} + 3.375G_{MC}$ Adjusted $R^2 = 0.768$
8. $V_{85LCV\text{-}PC} = 41.569 - 0.022L_C + 0.427\Delta - 1.09G_{PC}$ Adjusted $R^2 = 0.637$

3) Model for PC50

9. $V_{85CAR\text{-}PC50} = 50.167 + 0.194L_C - 0.307\Delta + 3.69G_{MC}$ Adjusted $R^2 = 0.656$
10. $V_{85TW\text{-}PC50} = 51.257 + 0.175L_C - 0.258\Delta + 1.897T_L$ Adjusted $R^2 = 0.484$
11. $V_{85HCV\text{-}PC50} = 32.924 - 59.391/R + 0.202L_C - 0.44\Delta + 7.55G_{MC}$ Adjusted $R^2 = 0.862$
12. $V_{85LCV\text{-}PC50} = 44.022 + 0.081L_C - 0.369\Delta - 1.34G_{MC}$ Adjusted $R^2 = 0.64$

B. 98th percentile speed estimation model development

1) Model for MID CURVE

13. $V_{98CAR\text{-}MC} = 44.053 - 0.062L_C + 0.863\Delta + 860/R$ Adjusted $R^2 = 0.63$
14. $V_{98TW\text{-}MC} = 57.078 - 0.405T_L - 1412/R$ Adjusted $R^2 = 0.56$
15. $V_{98HCV\text{-}MC} = 46.78 + 0.062L_C + 0.37\Delta - 2.98G_{MC}$ Adjusted $R^2 = 0.44$
16. $V_{98LCV\text{-}MC} = 50.987 - 1.165G_{MC} - 1.339G_{PC} + 1.51G_{PC50}$ Adjusted $R^2 = 0.426$

These models indicate that the 98th percentile speed of all vehicle types [Eqs. (13), (14), (15) and (16)] can be estimated from its 85th percentile speed at the midcurve region. The 85th percentile speed estimation model of car at midcurve is dependent on geometric parameters. But for other vehicle types (i.e., LCV and HCV) it is dependent on the 85th percentile speed at PC [Eqs. (3) and (4)], which in turn depends on its 85th percentile speed at 50 m prior to PC [Eqs. (7) and (8)]. The 85th percentile speed of LCV and HCV at 50 m prior to PC depends on the highway geometric features [Eqs. (11) and (12)]. For example, the 85th percentile speed of LCV at 50 m prior to PC depends on length of the horizontal curve. Researchers have noted that the speed at mid-curve can depend on approach tangent speed (04).

C. Speed Model of Car and Two-Wheeler

The 85th percentile speed of car at midcurve [Eq. (1)] is reliant on curve length (LC) and deflection angle (Δ). Note that the 85th percentile speed of car increases with increase in LC, but decreases with increase in Δ. The influence of LC and Δ on the 85th percentile speed of car is in conformation with the available literature (02). Possibly, longer curves with a similar deflection angle appear pleasing and make the car driver comfortable even at higher speed. Likewise, curves with larger deflection angle but similar curve length may appear kinky and discontinuous making car drivers uncomfortable. In other words, longer curve with lower deflection angle would encourage higher speed. Highway designers can effectively manipulate these two geometric parameters to achieve the desired operating speed of cars in the horizontal curves.

The 98th percentile speed of car at midcurve can be predicted from Eqs. (13). Considering the adjusted R2 values of these two equations, Eq. (13) may be preferred to estimate the 98th percentile speed of car at the midpoint of a horizontal curve. Further, the speed predicted from one of these two equations might be useful to compare with the adopted design speed of a horizontal curve for consistency and safety. Eq. (13) indicates that the 98th percentile speed of car at midcurve increases with increase in LC and is in conformation with the 85th percentile speed estimation model. Likewise, the 98th percentile speed of car at midcurve is found to increase with radius and is in conformation with speed estimation models available in literatures (08). For same curve length, the deflection angle reduces with increase in radius, and hence the speed is expected to increase.

D. LCV and HCV Speed Model

The 85th percentile speed of LCVs and HCVs at midcurve [Eqs. (3) and (4)] were eventually found to be dependent on its 85th percentile speed at 50 m prior to PC. The 85th percentile speed of LCV at 50 m prior to PC [Eq. (12)] depended on LC only. But for HCVs [Eq. (11)] it depended on Δ and gradient at 50 m beyond PT (GPT50). Eye height of drivers in LCVs and HCVs is higher than a car and thus has longer clear view along a highway. Further, acceleration and deceleration rate of LCVs and HCVs are lower than a car. Knowledge of upcoming road geometry and lower deceleration rate could make commercial vehicle drivers choose appropriate desired speed well before entering a horizontal curve. The 85th percentile speed of LCVs at 50 m prior to PC indicated that alike cars, longer curve length encourage higher LCV speed. The eye height of HCV drivers is usually higher than LCV drivers. Possibly, it makes them cognizant about vertical gradient beyond the horizontal curve and influence speed at 50 m prior to PC as well. The influence of vertical gradient beyond the horizontal curve on HCV speed is in conformation with the literature (06). However, the positive effect of deflection angle on HCV speed remains unexplained in this study and requires further investigation in future. The 98th percentile speed of HCV can be obtained from Eqs. (15). Considering the adjusted R2 values, Eq. (15) might be preferred to estimate the 98th percentile of HCV at midcurve. However, these equations indicated that geometric features such as gradient at PC and LC could influence the 98th percentile speed of HCV.

VI. Model Validation

The developed models were validated using data from two sites, not used in the model development. It was found that the root-mean square error (RMSE) values for the 85th percentile speed of car, two-wheeler, LCV, and HCV were 4.56, 8.36, 5.38, and 7.32 km/h, respectively. Similarly, it was 6.96, 8.34, 7.19, and 8.50 km/h. when the 98th percentile speed of car, LCV, and HCV were estimated from its 85th percentile speed at midcurve. These values were within the range reported in the literature (Jacob and Anjaneyulu 2013; Gong and Stamatiadis 2008; Semeida 2013; Morris and Donnell 2014).

VII. Sensitivity Analysis

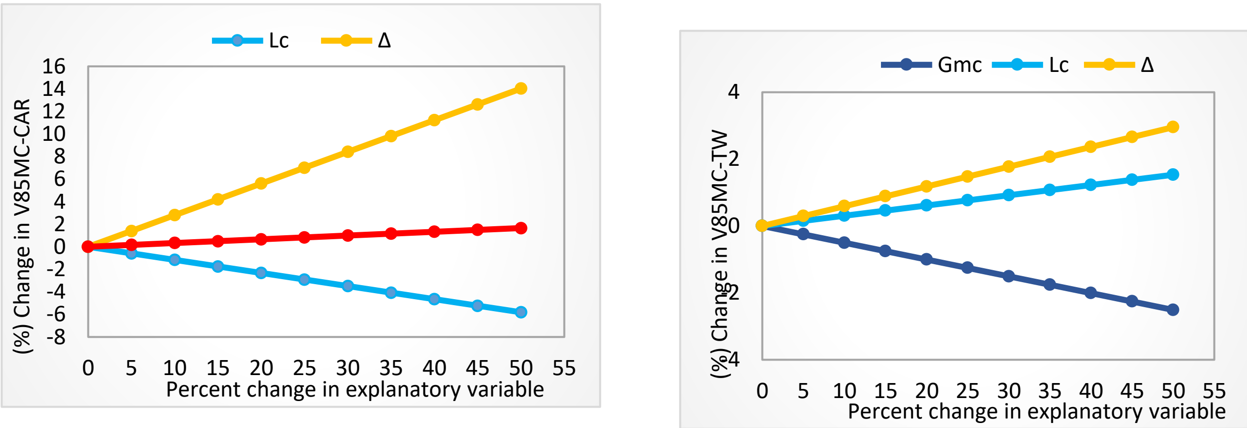


Figure 8 sensitivity Analysis

Sensitive analysis revealed that car speed is greatly influenced by Deflection angle. similarly, TW, HCV and LCV speed was highly impacted by Tangent Length, GMC and GPC respectively. That means change in explanatory variable leads to a higher change in speed. The similar results were found for sensitivity analysis of 98th percentile speed.

VIII. CONLUSION

The main objective of this study is to develop a 98^{th} and 85^{th} percentile speed estimation model. At first five category of vehicle (Passenger Car, SUVs, TW, LCV, HCV) were considered. Nevertheless, 98^{th} and 85^{th} percentile speed data of car and SUVs are not having noteworthy difference. Therefore, they were combined into one and represented as car for further analysis. Highway geometric features such as radius of horizontal curve, preceding tangent length, length of horizontal curve, deflection angle and vertical gradient, and the 85th percentile speeds in the preceding sections of highways were taken as independent variables for the model development using the stepwise multiple linear regression method. The 85th percentile speed of car and two-wheeler at midcurve was resulted to be reliant on geometric parameters. But the 85th percentile speed of LCV and HCV were resulted to be dependent on its 85th percentile speed at PC. Further investigation revealed that the 85th percentile speed at all five locations is influenced by length of curve and deflection angle.

Driver of the HCV and LCV get most influenced by gradient at curve locations. All explanatory variables of these models were found to be significant at 95% confidence limit.

The coefficient of determination value (i.e., adjusted R2 values) of the 85th percentile speed estimation model for car at midcurve was at par with similar models available in literatures (02). Although low, the coefficient of determination values of the 85th percentile speed estimation model for LCV and HCVat various locations were comparable with truck speed estimation models available in the literature (04). The cargo load and mechanical characteristics of LCVand HCV may affect its speed, but required data was not accessible for analysis in this study.

The values of the constant in the attained speed estimation models were also in conformation with available the literature (03). The curve length was found to be one of the statistically significant explanatory variables for predicting 85th percentile speed of all class of vehicle, and 98th percentile speed of car and HCV. This prompted a recommendation to include curve length in the present highway geometric design procedure. This study considered a limited number of geometric features and free-flow condition at mid-curve for developing the speed estimation models. Future research could consider the relationship between vehicle speed and additional independent variables such as vehicle platoon, roadside features, presence of vehicle in adjacent space and access density.

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