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Vehicle’s lateral placement on horizontal curves: A literature review

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Abstract

The placement of vehicle within a curve is a crucial factor with regards to safety as it influences its frictional requirement. The lateral placement of vehicle can be defined as the lateral distance from the centreline or outer edge of the road to the front tire of the vehicle. Limited study has been documented in the literature regarding this crucial element that affects the friction demand. Studies have been conducted to measure the effectiveness of surface treatments that take vehicle placement as a factor for safety analysis, but a lesser number of studies have concentrated on developing lane placement as a statistical model and have relied on statistical tests for comparability. This paper begins with an overview of prior research on the lateral position in conjunction with speed, followed by the different data collecting methodologies and equipment. Later part of the paper discusses the impact of lateral placement and the different modelling approaches proposed in the past. The findings reveal that there is a need to study the lateral positioning of vehicles on curves in greater detail so that better prediction models can be developed. A wide range of considerations including continuous evaluation along different categories of curves with different vehicle types and roadside configurations are needed to enhanced the existing models.

Keywords: vehicle trajectory, horizontal curves, driving behaviour, safety

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1. Introduction

About 1.3 million people die each year on the world's roads and between 20 and 50 million encounters non-fatal injuries. Road traffic crashes are the major cause of death among all age groups and the leading cause of death among those aged 15–29 years (Road Safety, WHO, 2018). Most of the road traffic deaths occur in middle and low-income countries with 54% of the world’s registered vehicles and deaths amounting to 90%. Reports from world health organization state that without sustained action, traffic crashes are to become the seventh leading cause of death by 2030 (Road traffic injuries, WHO, 2018). Road crashes can result from speeding, distracted driving, driving under influence of intoxicants, non-use of seatbelts and helmets, improper road geometry, unsafe vehicles, lack of law enforcement of traffic rules, etc. It is estimated that around 60% of crashes occur on two-lane rural roads outside cities or towns and half of these occur on curved sections. Accident analysis has typically shown that accidents on horizontal curves amount to 3 to 5 times higher than that on tangents sections (Lamm et al., 2007). Hence, safety evaluation of highways is of utmost importance, but this has been a matter of dispute since long. The lack of quantitative safety considerations in highway geometric design has been expressed by many researchers, and over the past few decades, several studies have been carried out to understand the basic characteristics and the various interactions of influential parameters of curves. Consistency in horizontal alignment is also important since sudden changes in road profile may shock the driver leading to critical speed and steering.

Speed can be said to be the most critical factor that is considered by road users while evaluating the relative efficiency of a route. Many speed models have been developed in different regions of the world as a safety measure, and it has been extensively used for design consistency models. Research has been mainly concentrated on two-lane rural highways with isolated horizontal curves.

Roadside departure is a serious safety concern, the substantial part of it occurs in two-lane rural highways. There are numerous elements involved in curve related crashes, a thorough understanding of these elements and their interaction can help in reducing these crashes. Some studies relating to the interaction between speed and vehicle placement have been conducted which aims to investigate the relationship of lateral position with speed as well as geometric characteristics along with the crash prediction. Curve parameters (such as the radius, length, presence or absence of spiral and tangential sections, degree and super-elevation) affect the speed changes along a curve leading to inconsistency in curve negotiation. Lane keeping is another vital factor, the failure of which contributes to improper curve negotiation which is studied using lateral position. The paper starts with an overview of the studies conducted and the models developed keeping design consistency as the prime focus. The review highlights the gaps of the existing studies, followed by proposing some insights for potential research directions.

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2. Horizontal curves characteristics

Literature review yields that a large portion of studies has focused on horizontal curves on two-lane rural highways. The typical characteristics include isolated curves which do not have intersections. A large number of studies have used constant lane width (Imran, Hassan, & Patterson, 2006) approximated lane width (Hallmark, 2014), two-lane and isolated curves (Fitzsimmons et al., 2013; Krammes & Tyer, 1991).

Horizontal curves' attributes and dynamic vehicle characteristics are the inputs in the design consistency models. Glennon (1971) analyzed the lateral path of vehicle with reference as the left edge of the left-rear tire. Speed, vehicle path radius, and lateral friction demand were calculated for each sample. For each sample, the critical point taken was the point of maximum lateral friction demand which coincided with maximum speed or minimum path radius. No correlation was found between speed and radii. Relations were developed between percentiles of vehicle path versus highway curve path and equation for vehicle path radius were derived in terms of highway curve radius. Spacek (2005) focused on typical track behaviors types of vehicles on curves and their frequency of observation and their inherent characteristics. The curves types were i) ideal ii) normal iii) swinging iv) drifting v) cutting and vi) correcting types. The study found that accidents might not be due to high speeds but due to steering corrections involved in certain track types. Imran et al. (2006) studied driver behavior and the discrepancy between path followed by vehicles and actual geometric alignment. Lateral displacement of significantly high values was observed in the first half of the curve. Along with entry transition curves, displacements were found to be constant with a slight increase towards the edge as it proceeded to the middle of the curve after which it tended to decrease. Stodart & Donnell (2008) presented a study on controlled nighttime driving by collecting speed and lateral vehicle position data on a two-lane rural highway. Changes in speed and lateral position were measured. Two significant parameters for lateral vehicle placement (LVP) differential were curve direction and curve radius. Drivers were found to shift laterally less by approximately 11 inches for each mile increase in the radius of the curve. Ben-Bassat & Shinar (2011) focused on evaluating the effect of different elements of roadway design on speed and lane position in an objective as well as subjective manner. In the simulated driving environment, constant lane width was considered. Results showed lane position to be affected by shoulder width in the presence of guard rails which throws light on perceived safety margins on driver behavior as the benefits of shoulder width decreases in guard rails' absence but not very significantly. Different road geometries were also found to have an impact on lane position as stability was maintained in straight sections and shallow curves, but as radii decreased, deviations in vehicle position increased. Fitzsimmons et al. (2013) found that time of day, the direction of travel, type of vehicle, speed and lateral position at point of entry have significant influence on trajectory profile. Jacob & Violette (2012) analyzed lateral position for cars and trucks and found that free-flowing cars at daytime followed centre of lane and tended to shift laterally for oncoming vehicles, greater shift observed in the case of trucks. The study showed no shift with the speed of vehicles because of oncoming vehicles. Fitzsimmons et al. (2013) reported that lateral position deviations were consistent neither between segment types nor between vehicle types. Mean trajectories and speed profiles were constructed with five stations along each curve, and the maximum deviations for passenger cars were compared to that of trucks. Cutting paths are observed for the majority of the vehicles and hence postulated that such behavior helps in maintaining the vehicle at higher speed. Among passenger cars and trucks, differences in lateral position were found to be higher in cars than trucks. The analysis also showed that maximum negative and positive deviations occur around the centre of the curve. Bella (2013) reported that driver adopts higher speeds on less demanding geometric elements and moves towards the centre of the curve on left-hand curves and towards the right side on right curves. Higher displacements were found to occur on sharp curves compared to those on shallow curves.

The preceding section summarizes an outline of the various factors and geometric characteristics used by researchers to gain an understanding of the driver behavior on horizontal curves.

3. Data collection methodologies and their impacts

Lane placement studies have been conducted as early as the 1970s. Glennon (1971) used a camera mounted on a vehicle to record vehicle paths. The recording vehicle followed the subject vehicle at a position headway of 60 to 100 feet. Five highway curve sites with curvature ranging from two to seven degrees were taken. After collection of data for each subject vehicle, the recording vehicle returned to its roadside position. Due to lack of advanced technology at that time, data sample was lesser in size and was prone to errors such as lateral discrepancy while placing reference markers, film parallax, length discrepancy of reference markers, equipment error etc. Analysis interval of 160 feet was chosen as higher interval would grossly overestimate the instantaneous radius. Spacek (2005) used 12 measuring units built into regular delineator poles which include an LCD display, ultrasonic sensor, infrared transmitter and receiver, electronic part with microprocessor, memory card holder, charge and batteries. The measuring unit was capable of measuring the transverse distance between vehicle and measuring pole. The track path was interpolated with third degree spline interpolation. In this study, exact measurements of lateral position were not used for evaluation but for categorization of vehicle paths into different path types. Smooth spline interpolation was used with the assumption that unstable trajectories with sudden changes in traffic do not usually arise. Some vehicle paths could not be categorized into the six path types defined and were summarized into another group called ‘remaining’ track path. More studies are needed to categorize these track path types so that a better understanding of driver behavior is obtained.

Stodart & Donnell (2008) collected data using two video cameras mounted over both rear tires in the experimental vehicle. The cameras were accompanied by a light to assist in illuminating the pavement markings. A third camera was also mounted to gather data from the speedometer. Field measurements were also taken using digital highway measurement (DHM) van along the two-lane rural highway of three-mile length considered as the study section. Data were captured at 0.1 second intervals and were reduced to point speeds, and lateral position at 15 m intervals and a total of 727 observations were made. The applicability of the lateral position equation becomes restricted as the lane and shoulder width were constant for the study section. Similar limitation of constant lane width had been observed in the study conducted by Ben-Bassat & Shinar (2011). Eleven male and seven female participants participating were asked to drive in a simulator. The driver behavior used to develop this model included the age group of only 23-31 years and diving experience of 5.5 to 13 years which might show significant variation to naturalistic driving patterns when gathered from all age and experience groups. The driving simulator used for the study was M400 of STISIM Drive (System Technology, Inc.) with three 19 inch screens covering 140º of the driver’s visual field. The use of simulator would have been more representational if different landscape elements such as houses and trees were added though the authors have tried to incorporate the various noises like that of engine, tires and brake noises. In case of real world driving, the presence of a posted speed limit has an influence in the driving behavior to some degree and hence it would have been more realistic if speedometer was not hidden from the participant. Driving simulator has also been used in the studies conducted by Bella (2013), Hassan & Sarhan (2012), Rosey & Auberlet (2012). The virtual three dimensional depiction of the road section is of utmost importance. It has been found that if the surroundings change although the road characteristics remain the same, it influences driver behavior. There has been debate about the usability of simulators by some researchers. Although it is advantageous in testing various conditions and suggested road improvements in simulators, discrepancies arise because the participants realize that they are driving a simulator and their alertness levels and safety concerns may not be as fully realized as in real world scenario. Low cost pneumatic road tubes were used to collect speed and positional data by Fitzsimmons et al. (2013). Z type configuration, similar to the one used by Finley et al. (2009) was adopted with two perpendicular tubes 16 feet apart with a diagonal tube in between and the setup was connected to a traffic classifier. Vehicle position was calculated from time stamped data, and vehicle type was classified into passenger cars and heavy vehicles. An urban and a rural study site were taken with ADT of 4380 vehicles and 1830 vehicles and speed limits of 45 mph and 55 mph respectively as the study sections. Data were collected at five stations between the point of curvature and point of tangency. 70 to 100 hours of data were collected during day and night time and during middle of the week, and after removal of outliers and errors, the final dataset used for analysis consisted of 21,686 passenger cars and 1634 heavy vehicles. A normalized lane width of 11 feet is considered for this study too. Use of pneumatic tubes, traffic classifiers and sensors is also seen in the works of Hallmark (2014), Geedipally & Pratt (2017) for the collection of data.

With the advent of new technologies such as GPS and GIS, assessment of driver behaviour has improved in terms of accuracy, time and costs. However, the integration of GIS and GPS also comes with problems such as bad and missing data points and lack of standard map matching algorithms. Imran et al. (2006) used differential GPS surveying to increase the reliability of the obtained positon data. Differential GPS uses ground base reference system to apply corrections to measurements at unknown sites. With one unit of GPS fixed at a control station near the highway, the other was fixed to the car to work as the Rover station. The raw GPS data was fed to SKIPro (Static-KInematic-Professional) software and processed. For centre-line of the highway, fitting of curves was examined at different speeds for both directions. Analysis of data points was done at 0.1, 0.5 and 1 second observation interval and compared which led to compromise in quality as interval increased. For lateral displacement, a digitized map was used which was developed from aerial survey with an error of ± 10m. The vehicle alignments were located on the west side of the actual alignment and this disparity is attributed to the error of ± 10m involved. The observed alignments are found to vary between 3 and 4m. This method depends on the availability of proper digitized maps, the accuracy of which directly influences the fitted alignment. Kozempel et al. (2014) provide a comparison between vehicle position provided by the DGPS and an inertial measurement unit (IMU). For data collection, two test vehicles were used for acquiring video data and GPS data. An urban traffic research car was used for the study, which had an extendable pole of height 13 meters, to which a camera system was placed. The study reports that no accuracy test was conducted during the study. Hence, although the IMU system manufacturer claims that with post processing and DGPS, an accuracy of less than 1 cm is attained in positioning, an accuracy level of 5 cm is assumed. The image processing was done with the help of a multi-sensor software (MUSE) developed by Institute of Transportation Systems at German Aerospace Center which processes data in order to detect, classify and track the objects of the video. The objects are tracked using Kalman Filter. Geo-referencing method was used for determining vehicle positions assuming the intersection to be the vehicle's centre. It had inherent accuracy problems because depending on the projection points being higher or lower; projection error occurs for too far or too near objects. Extended Kalman filter was used for tracking the positions which use position(x,y), angle, velocity, speed, acceleration and angular acceleration. The video data was validated with GPS data. Other studies using GPS technology for data collection are Maljković & Cvitanić (2016), Cerni & Bassani (2017), Eboli et al. (2017).

A comparison of data collected from Multi- GNSS and GPS-only approaches was done by Sun et al. (2017). The authors report that though Multi-GNSS is a promising approach, the possibility of bad satellite signals is always looming. The extent of data processing and cost are also a matter of concern since long hours of processing, as well as skills of GIS and surveying, are mandatory. The multipath biases and precision increases in the case of multi-GNSS because of increase in the number of satellites. A comparison of elevation angles at 20º and 35º was also performed which showed that better accuracy and precision could be obtained with 20º. Recent advances in technology for horizontal curves measurement include LiDAR. Among the few studies conducted using LiDAR, Holgado-barco et al. (2015) uses this technology in the form of mobile LiDAR for to semi-automatically extract the centreline of the road. Gargoum et al. (2018) proposes a method to extract curve data and its attributes automatically using LiDAR technology. The proposed algorithm is reported to be highly accurate. Recent technologies include advanced driver assistance systems (ADAS) where vehicle positioning is used to locate vehicle about other vehicles as well the road infrastructure, e.g. lane departure warning (LDW) system.

4. Modelling approaches

The relation between safety and highway features is of immense importance and there has been considerable number of researches to understand this relationship. Design consistency has concentrated mainly on two-lane rural highways. In a huge number of studies, operating speed models have been considered. Speed is a factor that is considered by user in selecting a route. The effectiveness and efficiency of a route is often perceived by the user in terms of speed, along with time and cost. But there are researches that show that mere speed considerations are not enough to understand the relationship between driver behavior and road geometry.

Glennon (1971) tried to generate a relationship between vehicle path radius and speed at the critical point of maximum lateral friction demand. Simple linear regression analysis was carried out on the data which gave a regression value of 0.114 i.e. a poor correlation was found out. Percentiles of vehicle path radius were plotted for each highway curve radius. A model was developed with 10% as the percentile level which would mean that only 10% of the vehicles will exceed a given path radius if it travels at design speed. The design equation followed at according to guidelines is as follows:

$$e + f = \frac{V^2}{15R} \tag{1}$$

where R is vehicle path radius. This equation assumes that highway curve radius is equal to vehicle path radius.

This equation was modified to

$$e + f = \frac{V^2}{7.86R} + 4030 \tag{2}$$

$$e + f = \frac{\left|D + 0.9\right|^2}{76100} \tag{3}$$

These equations were further modified to account for decrease in super elevation but failed to recommend a specific design standard based on the work as safety margins and skid resistance versus speed relation needs to be selected.

Stodart & Donnell (2008) explores the use of econometric modelling process to understand the lateral position behaviour along with ordinary least squares (OLS) regression and separate panel data models. The change in speed and lateral vehicle position from one station to next was used as the dependent variable.

$$\Delta V = V_{MPT} - V_{MC} \tag{4}$$

$$\Delta LVP = LVP_{MPT} - LVP_{MC} \tag{5}$$

ΔV=change in speed (mi/h); ΔLVP=change in lateral vehicle position (in.); V_{MPT} = speed at the midpoint of the approach tangent (mi/h); LVP_{MPT} = lateral vehicle position at the midpoint of the approach tangent (in.); V_{MC} = speed at the midpoint of the horizontal curve (mi/h) and LVP_{MC} = lateral vehicle position at the midpoint of the horizontal curve (in.). One objective of the study was to find if simultaneous relationship existed ΔV and ΔLVP. Since no significant relation is found between the two, the null hypothesis that OLS estimators are consistent cannot be rejected. Fixed and random effects models were also estimated. For ΔLVP random effects model, Breusch–Pagan Lagrangian multiplier test is carried out which gave a significant p value and hence not rejected. Also, the F test for equal individual effects is significant (p = .275) in ΔLVP fixed effects model which implies that OLS regression models with data pooled over all research participants can be considered. The simultaneous equations model suggest that random effects panel model is an improvement over OLS models. Finally, since ΔV and ΔLVP were not found to be significantly related, seemingly unrelated regression (SURE) model was finally used for analysis. Compared to OLS regression model, SURE model offers slight improvements in terms of efficiency. Average vertical grade indicator and curve radius are found to be negatively related to lateral vehicle position whereas curve indicator, speed at midpoint of upstream curve, hazard rating indicator and approach tangent length showed positive relation.

Fitzsimmons et al. (2013) evaluated speed and vehicle trajectories by comparing the medians of adjacent stations along one urban and one rural curve. It started with the null hypotheses that medians of adjacent stations are equal. It was rejected because speed and lateral position were not found to be constant along the curves. Four segments were categorized between five stations, and deviation values of each segment were calculated based on the difference between adjacent stations. A positive deviation indicated that vehicle is moving towards the centerline of the road and vice-versa. A non-parametric two sided Wilcoxon sum rank test was used to analyze the data and find the median and 95% confidence interval of the difference between the samples. It was found that vehicle lateral position changed significantly along sections of the curve. Comparison of lateral vehicle position between passenger cars and heavy vehicles were also performed with one sided Wilcoxon sum-rank test. Results showed that speed-distribution median of passenger cars is greater than the maximum speed distribution median of heavy vehicles. A cutting behavior was found to be followed by the drivers in which vehicle is shifted toward the centerline to exit the curve. Fitzsimmons et al. (2013) also evaluated the operating speed and lateral position for the same curves using linear mixed effects model. A single vehicle is used for negotiating the curve for repeated measurements along the curve. It was hypothesized that curve entry speed and lateral position be taken as independent variables which would predict the values of these variables at subsequent stations. In linear mixed model, data is allowed to have correlation and non-constant variability. SAS is used as a statistical package to fit the models. The general form of the models is given as follows:

$$Y_{speed(i,j)} = \alpha_0 + \sum_{k=1}^{p} \alpha_k X_{ijk} + e_{ij}^{*} \tag{6}$$

$$Y_{lateralposition(i,j)} = \beta_0 + \sum_{k=1}^{p} \beta_k X_{ijk} + e_{ij}^{*} \tag{7}$$

where Y Speed(i,j) and Y Lateral Position(i,j) are speed and lateral position dependent variables for vehicle i at station j, α_0 and β_0 are the constant intercept terms, and αk and βk are the population-specific regression parameters similar for all vehicles. Results of the model showed that both the curves sites operated very differently. The authors report that from the traffic operations viewpoint, the models do not have much relevance based on significant variables estimate. The results would be much better if a large number of varied sites were taken for developing the models with greater variation in road geometry. However, the model helps in confirming the fact that drivers tend to follow cutting behavior in both directions of travel.

Hallmark et al. (2014) developed separate models for left and right lanes of curves to gain a better understanding of ‘normal driving’ on curves. With data for 17curves, independent variables taken were offset and the amount the driver exceeded the posted speed. Generalized least squares model was used for analysis. For the inside curves, the vehicle tended to shift towards the edge of the road near the center of the curve than in the upstream section and hence more prone to roadside departure. For the outside curves, vehicles which travel to the right of the lane center at the upstream continues that path throughout the curve. The authors report that setting boundaries for driving behavior outside normal driving was not practical because data related to lane position were not of considerable reliability. Delineation of curves was also suggested by the authors as the vehicles tended to shift more towards the outer lane during night time. The main drawback of the study was that due to data reduction, the final sample size is small and hence not applicable to different types of curves.

Many studies related to lateral positioning of vehicles concentrate more on the statistical tests rather than development of models. A lot of research has also been concentrated on before and after studies and simulations with different road configurations where treatment effectiveness has been analyzed. Ben-Bassat & Shinar (2011) used ANOVA tests with repeated measures to study the effect of shoulder width, guardrail existence and roadway geometry on speed and lane position. One limitation of the study was constant lane width as pointed above. It was reported that standard deviation of lateral positions showed an interesting phenomenon that lane position variance was much higher when driving through sharp left curves without guardrails than in other geometries. Lateral positions were not found to be affected by road side elements such as guard rails. ANOVA test was also used to find the stability of the vehicle in traversing the curve. The standard deviations of the lateral positions were found to be significant in sharp curves. MANOVA test was used in a study conducted by Bella (2013) where vehicles tended to move closer to center when guardrails were present. Additionally, analysis carried out between standard and red-and-white guardrail showed that effect is more prominent in case of red-and-white guardrail, though not significant statistically. Statistical analyses showed that road geometry and cross-section directed the driver behavior and it did not depend on various road side elements.

Maljković & Cvitanić (2016) analyzed vehicle stability and driving behavior for finding design consistency of curves. Changes in curve radii and critical 15th percentile path radii were studied to understand the factors causing the differences. Out of the different geometric characteristics, curve length was found to have a significant effect on changes in radii. Confirming other studies, the vehicle trajectory was found to be sharper than the road alignment. The limitation of the study was the absence of variation in curve geometry such as spiral sections. The data was modelled using logarithmic step-wise regression model with length of curve as independent variable. Side friction demand factors were calculated which proved to be higher than side friction demand for 43% of the curves.

Cerni & Bassani (2017) used a good number of lateral position data to develop two naturalistic driving behavior models. The first model determines the “dimensionless average curvature difference” which is basically the difference between curvature of geometry and that of the vehicle path. This model is an attempt to explain how the unification of curve radius and deviation angle affects the driver behavior. To analyze the ramifications of improper road geometry and its effects on driver behavior, the second model assesses the paths followed by vehicle as a function of shape of the road geometry. The authors claim that these models are applicable to other road geometries when aided with calibration. However, it is to be noted that the absence of permitted safety margin restricts the applicability of the model.

Geedipally & Pratt (2017) uses Multinomial Logit model to describe the probabilities of occurrence of different path types as defined by Spacek (2005). The model included a deterministic and a random element. The curves were divided into three classes- a) ideal and normal b) cutting, swinging and drifting and c) correcting path type. The deterministic element included quantifiable variables that influences the path type directly such as skid number, lane width and deflection angle. The random element included unexplained factors that influenced path type. A high skid number value and expanded lane widths reduces the probability of vehicle following risky paths. Deflection angles’ effect on path type is found to be insignificant. Similar limitations of applicability because of data collection site being of only two lane highways along with the absence of variability in geometry such as transitions and spirals are found in the study.

Ghasemzadeh & Ahmed (2018) uses the Strategic Highway Research Program (SHRP) 2 data to study the lane keeping ability of vehicle in rain. Logistic regression is used to model the lane keeping behavior in which appreciable interactions were observed among weather, curve, traffic conditions, age, driver millage last year, number of lanes, and speed limits. Multivariate Adaptive Regression Splines (MARS) model has also been used to develop the lane keeping model with Standard Deviation of Lane Position (SDLP) offset as the dependent variable. MARS Model is a multivariate regression which combines recursive partitioning and spline fitting which sustains the positive aspects of both and less vulnerable to the negative aspects. It uses a local subset selection strategy which is one of its advantages. But it suffers from the disadvantage that with too many interactions, the applicability of the model reduces. SDLP is a binary variable with two levels including SDLP less than 20 cm and greater than 20 cm. Previous use of SDLP has been seen in the works of Zhou et al. (2008) and Brookhuis et al. (2003). It was found that weather conditions did not have a linear relationship with SDLP. Regression analysis showed that heavy rains forced drivers to be 2.2 times more prone to poor lane-keeping than clear weather. The applicability of micro-simulation models in preventing accidents is huge, and future studies with more detailed micro-behavior can lead to better technologies in transport safety.

4. Concluding remarks and direction for future research

This paper presents a review of existing literature on the lateral position of vehicles on horizontal curves. The different factors contributing to the positioning of the vehicle on a curve and its relation to speed (operating and 85th percentile) were compared. The various data collection methodologies used over the decades from video cameras to advanced LiDAR and LDW systems and their benefits and implications have also been presented.

A synthesis of the literature indicates that operating speed model is among the widely researched topic for design consistency models. Although there have been studies related to vehicle placement on curves, a limited number of factors have been analyzed. Extensive studies relating to the negotiation of different vehicle classes on different types of curves and the interaction among them can lead to significant insights which help in the improvement of the prediction capabilities of the current models. With the advancement in technology, the use of driving simulators has been increased. How simulator experiments differ from data based on the real-world driving pattern is of immense importance. Simulators offer ease of data collection over a real vehicle as in driving simulators, the opposing traffic, roadside configurations, and weather conditions can be easily controlled based on the focus of the research while such control is not possible in real-world scenario. Fatal driving circumstances can be created without putting lives at risk. However, the use of sub-standard simulators may result in unrealistic and faulty data. Realistic studied on safety in driving simulator are another concern as the participants are aware of the fact that there is no real risk involved. This is another area of research which needs wide exploration. With standard simulated 3D environment at nominal prices coming up, driver behavior can be studied with greater ease and at micro-level. Currently, the paucity of standard ways to accessing design consistency regarding vehicle placement on curves, and increasing safety concerns leads to enormous scope for its future research.

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