VEHICLE SWEPT-PATH AND DRIVER BEHAVIOUR AT SHARP CURVE SECTIONS OF "A" CLASS ROADS IN SRI LANKA

G. R. M. S. Gunarathna[a] and Vasantha Wickramasinghe[b]
[a,b]Faculty of Engineering, University of Peradeniya, Peradeniya, 20400, Sri Lanka
E-mails: muditha.sg@gmail.com, vskw@eng.pdn.ac.lk

ABSTRACT-When comparing traffic accidents on tangent and curving road sections, it is four times higher for curved sections compared to tangential sections. Therefore, identification of the vehicles' trajectories in sharp curves is important to improving the safety features of roads. There will be considerable deviations in real driving behaviour, which leads to traffic accidents. This research studies the patterns of vehicle trajectories by using naturalistic driving data with low traffic volumes. According to the results, there is a visible deviation between a real vehicle path and a model vehicle path generated by software especially in the mid location of the hair-pin curve. As a conclusion, some modifications in hair-pin curves are needed such as widening at entrance and exit locations of the curve to facilitate slow and smooth turning behaviour along the increased curve length of the hair-pin curve.

Keywords: Traffic accidents; Swept-path; Vehicle trajectory; Driver behaviour; Geometric design

1. INTRODUCTION

Most previous studies have used specific vehicles with specific drivers or instrumented vehicles to study the behaviour of drivers in sharply curved bends (Ilić et al., 2018; Xu et al., 2018; Yu et al., 2021). For the maximum variations of the vehicle trajectories, free flow conditions must be presented, as the drivers have a high degree of freedom when driving on two-lane roads with low traffic volumes (Yu et al., 2021). This research therefore studies the patterns of vehicle trajectories by using naturalistic driving data from Sri Lankan roads with low traffic volumes.
Xu et al. (2018) studied the trajectories of passenger cars on two-lane mountain roads. They observed the natural driving behaviour in free-flow conditions. They found different types of typical track patterns. Also, they found a relationship between the trajectory variation and the radius of the curve. That is, vehicle trajectories show low variation when the radius of the curve increases. However, the trajectory of a vehicle was poorly aligned with the centerline of the road at the bend (Gracia and Diaz, 2000). That is, the radius of the vehicle trajectory at the curve is significantly greater than the designed radius of that curve. This phenomenon is called "curve-cutting" in real driving behavior, and the main purpose of curve-cutting is to flatten the track radius, according to Yu et al. (2021). Most previous studies show a decreasing relationship between the variation of trajectories' lateral relative location and increasing radius, deflection angle, and speed.

According to the majority of the previous studies, the most significant factors that affect the turning vehicle paths are, curve radius, approaching speed, initial position of the vehicle when it enters a curve, type of vehicle, turning angle, number (or width) of exit lanes. This study aimed to determine whether there is any deviation between a real vehicle path and a model vehicle path generated by computer aided design software, and if so, how much deviation is there and what guidelines should be implemented for road safety and geometric designs.

2. MATERIALS AND METHODS

A sharply curved (hair-pin) bend was selected from the "18 Bends" area on the A26 road in Sri Lanka for this study. Firstly, six hair-pin bend locations were identified for the data observations. Both uphill and downhill traffic movements were considered to identify the effect of road gradient on driver behaviour. There were 12 events for this study with that both directions. The horizontal alignment of the curves was used to scale the drone video images to the correct size and measure the radii of those bends as the initial data for this study.

When considering mixed traffic on Sri Lankan roads, five types of vehicles (car, SUV and pickup, van, bus and truck with 2 axels) were observed for their trajectories. Therefore, 60 data sets were observed as the data collection. 25 vehicle trajectories were recorded from each data set for this analysis. Vehicle type and dimension, vehicle speed, and the radius and deflection angle of the curve were observed from the recorded videos. The type of gradient (uphill or downhill) of the road was recorded at the site. This study considered free flow conditions similar to the level of service "A."

Images were captured in a one-second time interval over the entire travel time of each vehicle crossing the considering bend and scaled into the actual dimensions using Autodesk AutoCAD 2020 software. Then the trajectories were generated from those images and all trajectories of one data set were plotted in one drawing. Then outer-most lines were identified as its swept-path. The curve start point, the curve mid-point and the curve end point are identified as critical sections at the curve. These critical sections were analyzed separately and statistically. A frequency diagram called Lateral Trajectory Density Distribution (LTDD) was generated for identified critical sections. It is the variation of the covered (swept) width of the vehicle over the cross section at a critical location.

The use of modelling techniques is a common practice in the design of hairpin curves. The design vehicle swept-path was identified as the optimum vehicles' swept-path without affecting the incoming traffic in this study. Autodesk Vehicle Tracking 2020 software was used to generate the optimal vehicles' swept-path as the most suitable path for the existing geometric features of the hair-pin bend. It was the Model Trajectory (MT). The swept-width of the MT of the corresponding critical section was identified after generating the MT for that curve, as indicated in the Figure 2.1. Deviations of LTDD from MT to the left-hand side (LHS) and right-hand side (RHS) were measured as mean and variance for each data set. Furthermore, that amount of deviation was statistically studied in order to arrive at a numerical outcome for the actual driving behaviours.

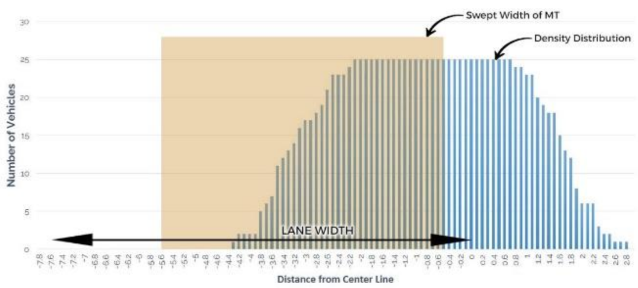

Figure 2.1: Frequency distribution of the swept-width of the vehicles and swept-width of MT.

3. RESULTS AND DISCUSSION

3.1 SPEED DATA

All vehicles showed higher speed at the curve start in downhill direction than their curve start in uphill direction due to the support of the gravity component, which increased the speed of the vehicle. Also, all vehicles showed a reduction in speed at curve mid (from curve start to curve mid) within the 30% ~ 60% range. Generally, a vehicle reduces the speed to turn the bend; hence, there were some amounts of speed reduction. All vehicles showed a gain in speed at the curve end (from the curve mid to the curve end), with a large variation in the amount of speed gain.

3.2 VEHICLE DEVIATION DATA

The deviation of a vehicle was calculated by comparing the observed swept-path with the model swept-path of that vehicle as indicated in the Figure 3.1. There was no visible deviation in the outer uphill and downhill directions for all vehicles. But only trucks and buses showed significant deviations at the inner curve in uphill and downhill directions. There was no visible deviation in the curve mid between the outer uphill and downhill directions for cars, SUVs, pickups, and vans. But the trucks and buses showed a significant deviation in the outer uphill and downhill

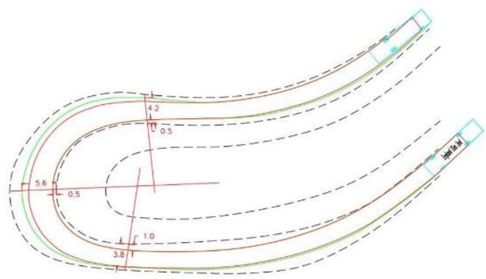

Figure 3.1: Dimensions of deviations of MT of bus driven uphill direction of 8th bend.

directions. Only buses showed a significant deviation at the curve end due to the higher length of the vehicle compared to other types of vehicles.

3.3 VEHICLE DRIVING BEHAVIOUR

All vehicles tried to maintain a single value of curve radius throughout the entire curve. Although the bend has an asymmetric curve, vehicles tried to follow a symmetric curve. Though there is enough curve radius to turn the bend, there were some center line cuts by cars and SUVs to maintain a single curve radius throughout the entire curve. Therefore, it is a very dangerous situation to keep asymmetrical bends. SUVs, vans, buses, and trucks showed center line cutting behaviour in order to increase the curve radius, especially in bends with a lower curve radius. When considering the radius of the curves, a vehicle requires the minimum value of the curve radius in order to make a turn without cutting the center line or entering the opposite lane. Different types of vehicles show different minimum radius values according to the physical dimensions and steering abilities of the vehicle.

4. CONCLUSION

In this study, actual driving behaviour was observed under natural and free flow conditions on a set of hair-pin bend curve locations. Swept-paths of 5 vehicle types at 6 hair-pin bends, including both uphill and downhill directions, and inner and outer curves, were collected using drone video recordings. Then driving patterns were analyzed, and the identified factors affecting the vehicles' swept-path are, type of vehicle, road gradient, curve situation (inner curve or outer curve) and, radius of the curve.
The other main findings are summarized as follows:

1) Vehicles try to maintain a single value of the curve radius throughout the entire hair-pin curve.
2) Vehicles follow a parabolic-shaped path before entering and after exiting the curve.
3) Vehicles follow a symmetrical path along the bend, though the actual bend is asymmetrical.
4) Center line cutting is happened in order to maintain a single value of the curve radius or to increase the driving radius of the curve, especially in bends with a lower curve radius.
5) With increasing the lane radius, the deviation of vehicles' swept-paths from the model trajectory is reduces. The most critical vehicle is the bus within the observed vehicle category, and the bus requires a minimum lane radius of 13m; hence, the minimum radius of the road center line becomes 16m for a 2-lane highway.
6) The minimum radius for the left edge of the inner lane should be 10m.

The following guidelines are proposed according to this study on hair-pin bends:

1) The minimum lane radius is 13m (this study confirmed the value given GDSR-RDA). Therefore, the minimum radius of the centerline will be 16m for a 2-lane highway.
2) Parabolic elements should be used before and after the single curve of the hair-pin bend. The length of this parabola will be about 25m.
3) Lane width at curve mid should be 6m for the inner curve and 5.5m for the outer curve.
4) The overall geometry of the curve should be symmetrical.

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