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The Impact of Road Alignment toward Road Safety: A review from statistical perspective

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Abstract Road safety is a key issue and has a considerably important consideration worldwide. Road accidents have caused serious economic and social hazards. Therefore, analyzing alignment consistency can significantly improve its safety performance. This paper aims to briefly review the effect of the alignment elements on road safety from previous studies. It is including to explain the statistical models used to evaluate the impact of road alignment on road safety. The important findings found that Linear regression and Poisson regression were commonly used in previous studies to disclose the effect of independent variables on road safety. Meanwhile, Negative Binomial Regression was commonly used to high light the relation between horizontal alignment and accident rate. The results from the statistical models also can be concluded that by improving the road alignment it is possible to the road accidents.

Keywords: road alignment, road safety, accident models.

1 Introduction

Road accidents represent a serious problem among other global hazards worldwide by inflicting undesirable effects on socio-economic aspects of the countries and their development. A report by World Health Organization (WHO) revealed that traffic accidents have caused the death of more than 1.25 million people each year which indicated that low- and middle-income countries have recorded 90% of the world's fatalities on the roads WHO (2019). Most of the world traffic engineers perceived that the driver is the major cause of road accidents. All the causes of unknown accidents, which were reported by the police patrols, were attributed to drivers. GWC Injury Lawyers (2018) showed that when police are called for completing Illinois Traffic Report to specify a car accident, the driver supposed to be more at fault for the incident would normally be listed as Unit 1. However, that police report does not inevitably present an absolutely accurate picture of the accident. Generally, the responding officer will not have witnessed the crash itself. As a substitute, that officer will be piecing jointly what happened based on the statements of the drivers involved. Besides, the road environment such as horizontal and vertical alignment also actually could cause road accidents. Road alignment is placed of special interest due to the higher risk of traffic accident also additional centripetal forces exerted on a vehicle, driver exceptional and other factors. Therefore, this paper aims to review and highlight the findings and conclusions of previous studies on the impact of geometric design on road accident (Hummer et al., 2010).

2 Modeling Horizontal Alignment and Road Accident Relation

Horizontal road alignment is one of the general features that affect driving and safety considerably.

It is composed of straight segments (tangents) connected by horizontal curves (and o ther elements of transition). According to PIARC Road Munual Safety (2018) declining curve radius increases the risk of a crash (i.e. as a turn becomes tighter). The risk for curve radii below 400 m increases faster. The risk of crashing is also higher in isolated curves (or where the driver might not expect it), and lower in a sequence of similar-standard curves for curves. Jacob et al. (2013) developed a model to forecast the operating speed at midcurve and tangent, the standard deviation of speed and mean speed at midcurve, and speed reduction from tangent to the curve.

Model (1): Operating Speed Models on Tangent

$$v_\tau = a_\circ + 3.6(PTLS^{a_1})$$

,where the model parameters $a_\circ$ and a_1 were considered for each group of vehicle and for all vehicles together. PTLS = length of following tangent in meters up to the speed observation point.

Model (2): Operating Speed Models at Midcurve

$$v_{85} = a_\circ - (Geomatric\ \ variable\,)$$

,where $a_\circ$ = maximum 85th percentile speed observed and f(·) = function of geometric elements such as, radius, length of curve, and deflection angle.

Also, they studied speed reduction from tangent to curve to clarify the function of radius, curve length, and approaching tangent speed. Speed reduction was set up to decrease with an increase in radius and curve length besides with a decrease in tangent speed. Operating speed on horizontal curves of two-lane rural highways is highly impacted by the length of the approach tangent and the radius and length of the curve.

Four regression models: Two Poisson regression models and two conventional linear regression models were used by Miaou and Lum (1993). The models showed road accidents and the geometric of highway design relationships.

Model (1): The multiplicative linear regression models

$$Y_i = v_i[\dot{x}\,\beta] + v_i\,\varepsilon_i = v_i\left[\sum_{j=1}^{k} x_{ij}\beta_j\right] + v_i\varepsilon_i$$
$$\varepsilon_i \sim ind\ N(0, \sigma^2), \qquad i = 1,2,3, \dots, n$$

,where the y_i is a random variable, which represents vehicles involving a number in accidents on road section i during a period of one year, ß is a k x 1 vector of unknown coefficients of regression, the transpose of whih is denoted by ß' = (ß, ß 2, . . .ßn&), ε_i~ind N(0, $(0, \sigma^2)$ reads as the ai are normally and independently distributed with zero mean and constant variance σ^2 (> 0).

Model (2): The multiplicative linear regression model

$$Y_i + \delta = v_i\left[\beta_j\,(\prod_{j=1}^{k}(1 + x_{kij})^{\beta_j})\right]e^{\varepsilon_i}$$
$$\varepsilon_i \sim ind\ N(0, \sigma^2), \qquad i = 1,2,3, \dots, n$$

, where δ is a selected small constant (e.g., 0.01, O.OO1)

Model (3): The multiplicative linear regression model

$$Y_i \sim ind\ Poisson(\mu_i)\, or\ p(Y_{i=}\, y_i) = p(y_i)$$
$$= \frac{\mu_i y_i\, e^{-\mu_i}}{y_i!}\ i=1, 2, 3,\dots, n.$$

Model (4): The multiplicative linear regression model

$$\log(Y_I + \delta) \sim ind\ N(\theta, \sigma^2)$$
$$\text{,where } \theta_i = E(\log(Y_i + \delta)) = \log(v_i) + \beta_i + \textstyle\sum_{j=2}^{k}\log(1 + x_{ij}),$$
$$i = 1,2,3, \dots, n$$

The performance of Negative Binomial (NB) regression models and Poisson was investigated by Miaou (1994) to establish the relationship between geometric design and truck accidents. Three sorts of models were considered: Zero-inflated Poisson (ZIP) regression, Poisson regression, and NB regression. The NB model was the best in estimating the frequency road sections with zero truck accident involvement. On the other hand, the ZIP model was the best in estimating the road sections frequencies with one, two, and three truck accident involvements. The Poisson mode1 was the best in estimating the road sections frequencies with four or more truck accident involvement. Hasan et al. (2005) found that the presence of a spiral curve has an impact on the driver's perception of the horizontal curvature in the case of crest combination only. In addition, the length of the spiral curve has no effect on the driver's perception whether on crest or sag mixtures; the driver's misperception of the horizontal curvature will increase because the radius of the horizontal curve increases. However, the impact of the position of the vertical curve centre relative to the horizontal curve was not statistically vital; the perception drawback seems to diminish as the positive offsets will increase. And they investigated the impact of overlapping vertical alignment on the perceived horizontal curvature and, therefore, static and dynamic computer-generated three-dimensional presentations of the driver's road view were created. The results of both presentation methods (dynamic and static) showed that the hypothesis was valid. However, the hypothesis was more evident in the case of sag curves, which is a more serious issue with respect to road safety. The probability of erroneous perception, affected by vertical curves, increases when 1) the length of vertical curve per 1% change in grade decreases, 2) the horizontal curve radius increases, and 3) the sight distance increases. The driver's characteristics did not seem to affect the horizontal curve perception.

A three-dimensional static presentation was used to determine the mean value of the perceived horizontal curve radius for different alignment parameters. The researchers found that actual radius, type of overlapping vertical curve, turning direction (on crest and sag curves), and sight distance (on sag curves) have significantly affected the perceived radius. Also, simple statistical models were created using regression analysis to evaluate the perceived radius of any horizontal curve in a combined alignment (Hassan et al., 2007).

In a similar context, Fitzpatrick et al. (2010) improved Accident Modification Factor (AMF) for horizontal curve for a four-lane divided and undivided highway. They showed that the driveway density differs for the horizontal curves compared with the flat section. A negative binomial regression model was used to evaluate the impact of independent variables on road accidents. Aram (2010) analyzed the relationship between horizontal carvers of two-lane highway on traffic safety. In addition, various traffic volumes and mix, cross section, geometric features of curves, stopping sight distance, pavement friction, roadside hazard, traffic control devices, and roadside hazard all have an impact on the horizontal curve accident rate. Ibrahim and Sayed (2011) endeavored to bridge this gap by incorporating a reliability-based quantitative risk measure such as the probability of non-compliance (Pnc) in safety performance functions (SPFs). Creating this link will incorporate reliability-based design into the traditional benefit-cost analysis, which should allow a wider application of the reliability technique in designing roads. The reliability analysis was used in the First Order Reliability Method (FORM). Two Negative Binomial (NB) compared models with and without the reliability-based risk measures. It was found that the models, which incorporated the Pnc, obtained a better fit to the data set than the traditional (without risk) NB SPFs for total, property damage only (PDO) collisions, and injury and fatality (I + F). Obaidat and Ramadan (2012) predicted the relationship between the characteristics of accidents as a dependent variable and other studied variables as independent variables. The significant contributing variables at hazardous locations included the following: posted speed, an average and maximum degree of horizontal curves, number of vertical curves, type of road surface, number of verticals per hour, number of pedestrian crossing facilities and percentage of trucks, average running speed, and lighting (day or night). Fitzsimmons et al. (2013) provided the means to predict the vehicle speed and lateral position using linear mixed-effect regression models considering observations of the same vehicle along horizontal curves. The lateral position and speed at the point of entry were recorded to affect trajectory and speed profiles. The rural horizontal curve site models indicated that variables were significant and influenced both vehicle speed and lateral position: the direction of travel (inside or outside lane), time of day and type of vehicle. The variability of acceleration/deceleration and lateral position increased as a result of speed reduction, which was sustained throughout the entire urban area, higher workload when curves were present (versus absent) as peripheral detection task (PDT) performance (Ariën et al., 2013).

A recent study by Hosseinpour et al. (2016) showed that the Heterogeneous Negative Binomial (HTNB) was the best-fit model among others to model the frequency of rollovers. The variables Light-Vehicle Traffic (LVT), horizontal curvature, access points, speed limit, and centerline median were positively associated with the crash frequency, while Unpaved Shoulder Width (UPSW) and Heavy-Vehicle Traffic (HVT) were found to have an opposite effect. The findings of this study suggested that rollovers could potentially be reduced by developing road safety counter measures such as access management of driveways, straightening sharp horizontal curves, widening shoulder width, better design of centreline medians, and posting lower speed limits and warning signs in areas with higher rollover tendency. Xu et al. (2017) explained that horizontal curves recorded three times the crash rate more than other types of road segments and fatal crashes involved a single vehicle striking trees and leaving the road.

Suzuki (2019)used 3D-Cad to solve the geometric problems and found that using 3D-Cad can solve the problem more quickly than drawing based upon traditional descriptive geometry.

3 The Effect of Vertical Alignment on Road Safety

This includes the grade of the road (the vertical elevation change rate) and vertical curves (i.e. crests and sags). PIARC Road Manual Safety (2018) concluded that sag curves haven't any significant safety effect. On other hand, crests have significant effect on safety of road. De Pauw et al. (2014)investigated the impact of lane dimension, shoulder dimension, grade, side slope, and fastened objects close to the route; the horizontal and vertical curves were quantified. For the low-volume road sample, roads with lanes, which are twelve-foot wide have a higher crash risk than the roads with commonplace 12-ft lanes. Similarly, roads with slender or no shoulders tend to have higher crash rates than the roads with shoulders four-foot or five-foot wide. The crash risk is shown to be much higher on curves with higher degrees of curvature compared with curves with smaller degrees of curvature.
Fu et al. (2015) explained that the impact model of the mean curvature and torsion variations with road accident rates on adjacent sections of expressways and multilane highways was created. They also showed that horizontal and vertical alignments cannot be superposition, and the geometric continuity can degrade in several degrees once the two-dimensional style components are amended to guarantee geometric continuity in three-dimensional area. The limited amendment amounts of torsion and curvature have a strong correlation with traffic safety; the curvature continuity has the number one role. The major road three-dimensional alignment style satisfied the second-order geometric continuity at least.
The rate of crashes will increase as per changes in road geometry factors throughout the day and for eastward travel. This cannot be the case for night driv ing, whereby the incidence of crashes is comparable on each straight and curved roads segment because of the headlamp result and restricted background sight view. Also, crash clusters at day-time area attributed to the stronger result of road pure mathematics (e.g., a combination of curvature and vertical grade) on the driver's behavior travelling eastward. The results concluded that it is essential to think about the result of environmental factors in any road safety and crash analysis studies (Alian et al., 2016).

Kobryń (2017) provided an applicable approximation equations strategy for longitudinal profile points and development of the exploitation involving the method of least squares as a strategy to identify parameters for optimum vertical alignment. The proposed approach showed that the principles of the alleged polynomial routing are achievable to form the vertical alignment, which can be composed of each general shift curves and as line sections as well. Previous studies that investigated many longitudinal profiles on positioning explained that the projected approach allowed for an improved fit the vertical tract than ancient style ways of the vertical alignment, i.e., the exploitation tangent polygonal shape of parabolic arcs.

4 Conclusions

Previous studies concluded that the horizontal and vertical alignment element has a significant impact on road accidents. In addition, the suggested improvements included the degree of horizontal curvature, lane, shoulder, median, and widths to reduce accidents on the road. The horizontal alignment was linked to road accidents according to the following models: the Poisson regression model, the Conventional Linear regression, and the Heterogeneous Negative Binomial model, etc. The accident risk was found to be higher on the curves with larger degrees of curvature compared to the curves with smaller degrees of curvature.

The vertical alignment has limit studies that explain the model's relationship between there's elements and road accident. And the studies related concluded that Sag curves haven't any significant safety effect, while crests curves have a significant effect on road safety due to the sight distance. The probability of erroneous perception, affected by vertical curves, increases when; the length of vertical curve per 1% change in grade decreases, the horizontal curve radius increases, and the sight distance increases.

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