Int. J. Struct. & Civil Engg. Res. 2013

International Journal of Structural and Civil Engineering Research

ISSN 2319 – 6009 www.ijscer.com
Vol. 2, No. 2, May 2013

Research Paper

GEOMETRIC DESIGN CONSISTENCY MODEL BASED ON SPEED AND SAFETY IN RURAL HIGHWAYS IN SOME EUROPEAN COUNTRIES:A REVIEW

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In order to reduce road fatalities as much as possible, this paper presents a new method in evaluation of road geometric design consistency based on speed and safety in rural highways. The consistency model presented in this paper is based on the consideration of continuous operating speed profiles. Geometric design consistency studies can be used to identify inconsistent sections on highways, which can then be targeted for improvement. No geometric data exists for rural highways. A method of estimating geometric data from digital maps was implemented on some kilometer of highways. Elements were classified as good, fair or poor using a design evaluation criterion. A geometric design evaluation can be used to indicate locations on highways where accidents occur more. Improvement works can be concentrated on the sections and hence rural highways can be made safer.

Keywords: Road safety, Design consistency, Speed, Safety, Geometric design

INTRODUCTION

Road fatalities are a significant problem. The Road accidents are complex events involving a variety of factors, including highway geometry, driver behavior, weather conditions, speed limits and human factors. This paper focuses specifically on highway geometry, its effect on the speed of vehicles and its effect on safety. The fatal collision rate of an average rural single national road is approximately twice that of a dual carriageway road with at-grade junctions and approximately six times that of a motorway.

Road crashes are one of the most important problems in our society. Every year 1.2 million of people are killed and between 20 and 50 million people are injured due to road accidents. In European countries most of the accidents occur on rural roads, for example in Spain approximately 63% of rural road accident fatalities and in Ireland 57% of them occur on rural roads.

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Three factors may have influence on the occurrence of a road accident: human factor, vehicle and road infrastructure. Previous research has shown that collisions tend to concentrate at certain road segments, indicating that besides driver's error, road characteristics play a major role in collision occurrence. One of the main reasons for accident occurrence can be lack of geometric design consistency. This concept can be defined as how drivers' expectancies and road behavior fit. Thus, a road with a good consistency level is the one in which its behavior and what drivers expect are very similar, so drivers will not be surprised while driving along them. A poor consistency means bad fitting, surprising events and also high speed variability along different road segments and among different drivers, which may increase the likelihood of crash occurrence.

Most of the research and development of design consistency measures focuses on four main areas: operating speed, vehicle stability, alignment indices and driver workload (Ng and Sayed, 2004; Awata and Hassan, 2002). A simpler approach to evaluate design consistency can be based on the alignment indices (Hassan, 2004), which are quantitative measures of the general character of an alignment in a section of road.

Although most consistency criteria give thresholds for good, fair and poor design consistency, other authors (Hassan, 2004) suggest continuous functions as a better tool for designers.

The consistency criteria previously presented allow evaluating the design consistency and estimating road safety only in a road element (the horizontal curve). Other studies, such as the one carried out by Polus and Mattar (Habib, 2004), used continuous speed profiles to determine the global speed variation along a road segment, and determining a single consistency value for the whole road segment. Moreover, their design consistency index is a continuous function instead of being based on ranges.

They developed two new consistency measures. The first was the relative area bounded between the operating speed profile and the line of average weighted speed by length (*Ra*).

BACKGROUND

Generally, geometric design consistency measures are divided into four distinct categories: Operating speed, vehicle stability, driver workload and alignment indices.

Operating speed is defined as the speed selected by highway users when not restricted by other users (Poe *et al*., 1996), and is normally represented by the 85^{th} percentile operating speed. In terms of geometric design consistency, operating speed (V_{85}) is widely considered to be the most notable and straightforward geometric design consistency measure. The change in speed of vehicles is a visible indicator of inconsistency in geometric design (Nicholson, 1998). Several interpretations of operating speed as a geometric design consistency measure have been made in the literature. The operating speed can be used in consistency evaluation by examining the variation between the design speed (VD) and V_{85} on a particular section of highway or examining the differences between V_{85} on consecutive highway elements (ΔV_{85}). Safety criteria I and II (Table 1) show the most common set of criteria used to determine the level of consistency of a highway section in relation to operating speed (Lamm, 1988). Table 1 classifies highway sections into three categories. Where, Good = no highway alignment corrections are required; Fair = no alignment correction is required, but corrections may be desirable tosigns, camber etc.; and Poor = alignment redesign is recommended.

These are the most well known set of safety criteria. However, they may suffer from several shortcomings (Hassan, 2004). The safety criteria were developed from accident studies in New York and caution should be employed when implementing these models in other locations (Lamm, 1988).

Criterion I, for example, would suggest there is no difference between a value of 10.1 km/h for $|V_{85} – V_D|$ and a value of 20.0 km/h for $|V_{85} – V_D|$. They both lie in the same category—"Fair". But values of 19.9 km/h and 20.1 km/h for $|V_{85} – V_D|$ lie in two different categories, "Fair" and "Poor" respectively. This creates a step form of the two criteria and is a concern (Hassan, 2004). The same step from of criteria exists for Criteria II.

Criterion III is based on vehicle stability on horizontal curves. Vehicle stability is paramount in ensuring road safety. A vehicle negotiating a horizontal curve experiences excessive centripetal forces, vehicle rollover and head-on collisions can be attributed to these forces (Hassan *et al.*, 2001). Locations that do not provide vehicle stability can be considered geometric design inconsistencies. Safety Criterion III in Table 1 was suggested to evaluate design consistency through ensuring that enough side friction supply (f_R) is available to meet the side friction demand (f_{RD}) as the vehicles negotiate a horizontal curve. Side friction supply, often referred to as side friction assumed, on any given horizontal curve is calculated using the following formula (Lamm, 1991):

$$f_R = 0.25 – (2.04 \times 10^{-3} V_D) + (0.63 \times 10^{-5} V_{D2}) \quad ...(1)$$

This formula assumes a flat topography. A point mass formula is used to calculate f_{RD} (AASHTO, 2001):

$$f_{RD} = (V_{85}\ 2 / 127R) – e \quad ...(2)$$

where R = curve radius (m); V_{85} = operating speed on element (km/h); and e = super-elevation rate. Criterion III examines the difference between f_R and f_{RD} (Δf_R) on a particular section of highway. This criterion suffers from the same shortcoming as safety criteria I and II in that it creates a step form of criteria. The formulae were developed in the United States so again caution should be employed when implementing them in other countries. Both formulae are subject to substantial criticism in the literature. The friction values used to develop Equation (1) are based on research that was carried out in the 1930s and 1940s (Hassan, 2004). Measurement techniques have come a long way since then; they also would not take into account modern vehicle and tire design. Equation (2) treats the

Table 1: Design Evaluation Criteria

Design Evaluation	Criterion I	Criterion II	Criterion III
Good	$\|V_{85} – V_D\| \le 10$ km/h	$\Delta V_{85} \le 10$ km/h	$\Delta f_R = f_R – f_{RD} \le 10.0$
Fair	$10 < \|V_{85} – V_D\| \le 10$ km/h	$10 < \Delta V_{85} \le 20$ km/h	$0.01 > \Delta f_R \ge –0.04$
Poor	$\|V_{85} – V_D\| \ge 20$ km/h	$\Delta V_{85} \ge 10$ km/h	$\Delta f_R < –0.04$

entire vehicle as a point mass. It does not take into account the interaction between the vehicle tires and the pavement, which is the principal method of keeping a vehicle on the highway. Side friction is not easy to recognize and measure as operating speed (Hassan *et al*., 2001).

OPERATING SPEED

Operating speed (V_{85}) data was collected in order to formulate an operating speed model. This research was only concerned with cars. Data was collected by means of a spot speed survey. Sites for the spot speed survey were selected to cover the different highway characteristics on this type of road (e.g., different curve radius, length deflection angle and tangent length). Previous research has suggested that 50 spot speed observations at each site in each direction would be adequate to estimate the operating speed at each location (Hashim and Bird, 2005). Speed data was only collected in daylight hours on a dry pavement. All the selected sites had a speed limit of 100 km/h and were not near any junctions.

CONSISTENCY MODELS

For developing the design consistency parameter, the following process was carried out: in first place, crash rates were estimated for each road segment. Also, all operating speed profiles were determined, and by means of them, several variables were calculated. After this calculation, correlations among all variables were examined, and five of them were selected for calibrating the consistency model. The consistency model was calibrated by means of examining its relationship to safety, selecting one model that could be easily used for designing the road and it was related to safety. It was also intended to formulate an operating speed model for tangents on rural two lane carriage ways. However, one could not be formulated from the data. This has happened in previous studies; operating speed on tangents is more difficult to model than operating speed on curves.

RELATIONSHIP TO SAFETY

Considering the previous variables, several models were checked in order to analyze the relationship between the Estimated Crash Rate (ECR) and all variables separately. The strongest correlation to the crash rate is given by the division of the squared average operating speed and the average speed reduction value. Once the main expression was obtained, several attempts were made to add any of the two variables that were taken out from this analysis, but no good results were obtained. Thus, the proposed design consistency index is the following:

$$C = \frac{\bar{v}_{85}^{2}}{\Delta v_{85}} \quad ...(3)$$

Both speeds are in km/h and for 85 km/h, so the final index is also in km/h.

Analyzing its composition, road segments with lower average speed reduction value will lead to higher consistency values, due to the more uniform speed. Higher operating speed average values are associated to better, more consistent roads. It is worth to highlight that this model considers both the average speed and its variability. As a difference to other consistency indices, model only considers decelerations in its determination, instead of both acceleration and decelerations, represented in the standard deviation of the operating speed.

ACCIDENT ANALYSIS

The accident database for the N52 was obtained from the NRA; accidents from 1999 to 2005 inclusive were examined. The data base contained 533 accidents of varying degree. However, not all of these accidents occurred on the N52. Accidents that did not occur on the N52 were excluded. Only accidents that could have been caused by the alignment of the road were needed for analysis. These accidents were extracted in line with previous research (Anderson *et al.*, 1999). Only non-intersection accidents that involved the following were considered: (a) a single vehicle running off theroad, (b) a multiple-vehicle collision between vehicles travelling in opposite directions, or (c) a multiple-vehicle collision between vehicles travelling in the same direction. All accidents involving parking, turning, or passing maneuvers; animals in the roadway; pedestrians and bicycles or motorcycles were excluded. 53 accidents remained after the exclusions. These accidents occurred on 40 elements during the 8 year period. The accident locations were compared to the geometric design consistency evaluation. It was found that 19 of these accidents occurred in locations that were classified good, 8 accidents occurred in locations classified fair and 13 accidents occurred in locations classified poor.

CONCLUSION

Road fatalities are one of the most important problems in our society, causing thousands of victims every year. To contribute with the improvement of the road safety, this paper presents a new design consistency model that may be used as a surrogate measure for road safety evaluation of two-lane rural roads.

The consistency model has been developed from the regression analysis between several speed-measures variables and crash data.

The used speed-measures include not only variables related to operating speed but also related to deceleration and posted speed. All of them have been obtained from operating speed profiles built with the operating speed and deceleration/acceleration speed models developed in previous research. Those models were calibrated with continuous speed data recorded by an innovative technique that uses GPS devices for monitoring actual drivers' behavior. Thus, operating speed profiles are more accurate, presenting better approximation to the actual behavior of drivers.

The used crash data were not directly the observed accidents. With these accidents, a Safety Performance Function was calibrated showing an over dispersion of 0.1519. Then, based on this parameter and the observed accidents, the Empirical Bays methodology was applied to estimate more accurately the number of accidents and thus the crash frequencies. 14 operating-speed-related variables were obtained from analyzing the operating speed profiles, crash data and speed limits for all road segments. A correlation analysis was made in order to reduce final amount of parameters, reducing final number of variables to five, being candidates to be used in the final consistency model form. Also, some interesting relationships were found among variables, such as the higher crash rates reached when operating speed variability presents a medium value, or the high correlation between this parameter and the operating speed deviation.

At the same time we can also get the below results too:

- The method used to estimate the highway geometry detected more curves and tangents on the road surveyed in this study than a similar length of road surveyed in the UK. This suggests that rural highways undulate more in Ireland (the place where the researches study there) than in the UK.

- The mean operating speed on curves in Ireland is lower than that of roads in other European countries. This is to be expected as the survey conducted in this study was done on much tighter curves.
- A relationship exists between geometric design consistency and safety. Of the 40 locations that had accidents over the 8 year period from 1999-2005, 13 of these locations were detected as needing re-alignment by the geometric design consistency evaluation.
- Geometric design evaluations can be used to pinpoint locations on highways where accidents could conceivably be higher. Improvement works and resources can therefore be concentrated on these sections and hence rural highways can be made safer.

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