"Study on Geometric Design Consistency of Horizontal Curves on Two-Lane Undivided Non-Urban Roads under Heterogeneous Traffic Conditions"

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Abstract

Safety on rural highways is of great concern as nearly two third of road fatalities are found to take place on such roads. High speed of vehicles is the characteristic of rural highways. Geometry is one of the factors that control the speed of vehicles and consequently, the crash occurrence. A highway design can be evaluated based on consistency in geometry. Operating speed is the measure adopted for consistency evaluation in this study.

The objectives of this study are to develop operating speed models for different classes of vehicles at middle of the horizontal curve and operating speed reduction models from preceding tangent to the horizontal curve and then use criteria developed by researchers for evaluating the geometric design consistency on two lane rural highways.

Operating speed deviation from design speed at the middle of curve and operating speed reduction from preceding tangent to the curve are the consistency measures used in this study. These criteria can be used to evaluate the curve as a single element, and as successive elements. Alignment can then be classified as good, fair or poor using these criteria. Using operating speed deviation criteria, 69.7% curves were found to have good consistency for light vehicles and 100% curves were found to have good consistency for heavy vehicles on the selected road stretch. Using speed reduction criteria, 14% curves were having good consistency for light vehicles and 11.6% curves were having good consistency.

Keywords: Operating speed, design consistency, horizontal cure, radius of curve, deviation angle of curve.

1. Introduction

Traffic safety has become a growing concern for the public in general and highway professionals in particular. During the calendar year 2017, there were close to 4.8 lakh accidents in India which resulted in more than 1.49 lakh deaths and inflicted injuries 5.2 lakh persons. These numbers convert into one road accident every minute and one road accident death every 4 minutes. It is estimated that more than 30 percent of the total accidents can be attributed to the accidents that takes places on curved sections rather than straight segments. Thus curved sections represent the most critical locations while considering measures for improvement of highway safety.

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 behaviour fit. Thus, a road with a good consistency level is the one in which its behaviour 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.

Horizontal curves being the most critical locations prone to accidents are due to design inconsistency. This design consistency may arise due to disparity between operating speed and design speed at the middle of curve and disparity between operating speed between successive curve elements (a horizontal curve and a tangent). The disparity between operating speed and design speed at the middle of the curve and disparity between operating speed between successive elements are due to inadequacies in the design speed concept.

1.1 Objectives of study

i. Study driver's speed characteristics at horizontal curves on two-lane rural highways.
ii. Driver's speed choices on inside and outside lanes in each direction of travel will be studied.
iii. Identify the potential factors affecting driver's speed choice at horizontal curves.
iv. Develop models for predicting operating speeds at middle of curve.
v. Develop models for predicting speed reduction from tangent to the middle of the curve.
vi. Validate the models developed for predicting operating speeds at middle of curve and predicting speed reduction from tangent to the horizontal curve.
vii. Evaluate the design consistency of horizontal curves under study.

2. Evaluation of Design Consistency

The available methods for evaluating consistency are speed based, vehicle stability based, alignment indices based and driver workload based. Among the available methods, operating speed based approach can be reckoned as the most efficient and widely used. This is because speed is a visible indicator of consistency. For evaluating design consistency of highway alignment, operating speed prediction models at middle of curve and operating speed reduction models between successive elements are developed using the geometric parameters of horizontal curves and then the criteria given by Lamm et al. is used to evaluate design consistency (See Table 2.1).

Table 2. 1 Criteria's for Design Consistency Evaluation

Safety Criterion	Criteria 1	Criteria 2
Good	V_{85}-$V_d \leq 0$ km/hr	$\Delta V_{85} \leq 10$ km/hr
Fair	$0 < V_{85}$-$V_d \leq 9.7$ km/hr	$9.7 < \Delta V_{85} \leq 19.3$ km/hr
Poor	V_{85}-$V_d > 9.7$ km/hr	$\Delta V_{85} > 19.3$ km/hr

3. Data Analysis

Data analysis was done using the SPSS software. Data analysis includes three steps which are extraction of 85th percentile speed, normality examination and hypothesis testing.

3.1 Extraction of Speed Data

After collecting speed data from the field, following operations were performed using SPSS software.

i. First outliers for each curve for both classes of vehicle were removed from the data using box plots.
ii. 85th percentile speed (V_{85}) for each curve at each spot is then extracted for both light and heavy vehicles.
iii. Reduction in 85th percentile speed (ΔV_{85}) for each curve from preceding tangent to middle of curve for both classes is determined.

After extracting reduction in 85th percentile speed (ΔV_{85}), it was found that for 4 curves there was no speed reduction, so only 39 curves are available for speed reduction analysis.
The design speed was calculated using the following formula:

$$\boldsymbol{V = \sqrt{127 * (e + f) * R}}$$

The value of lateral friction (f) in above equation was taken equal to 0.15.knowing radius of curve (R) and available super-elevation (e) at a horizontal curve, we can calculate design speed.

4. Design Consistency Evaluation

4.1 Design Consistency Evaluation Using Criteria 1

The design consistency evaluation of the studied horizontal curves for light vehicles on the basis of Criteria 1 is shown in *Table 4.1*.

Table 4. 1 Design Consistency Ratings for Light Vehicles for Criteria 1

S.No.	Design Consistency	S.No.	Design Consistency	S.No.	Design Consistency
1	Good	16	Good	31	Fair
2	Good	17	Fair	32	Good
3	Good	18	Good	33	Good
4	Fair	19	Good	34	Fair
5	Good	20	Good	35	Good
6	Good	21	Fair	36	Good
7	Fair	22	Fair	37	Good
8	Good	23	Good	38	Fair
9	Poor	24	Fair	39	Good
10	Good	25	Fair	40	Good
11	Good	26	Good	41	Fair
12	Fair	27	Poor	42	Good
13	Good	28	Good	43	Good
14	Good	29	Good		
15	Good	30	Fair		

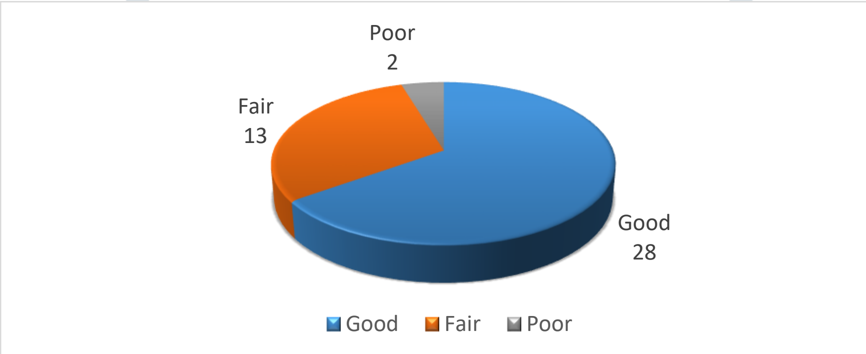

Figure 4. 1 Design Consistency Ratings for Light Vehicles Based On Criteria 1

From *Figure 4.1*, it was found that for light vehicles 30 horizontal curves had good consistency, 13 curves have fair consistency and no curve had poor consistency.

Design consistency evaluation based on Criteria 1 for heavy vehicles yield that all the studied horizontal curves had good consistency.

4.2 Design Consistency Evaluation Using Criteria 2

The design consistency evaluation of the studied horizontal curves for light vehicles on the basis of Criteria 2 is shown in *Table 4.2*.

Table 4. 2 Design Consistency Ratings for Light Vehicles for Criteria 2

S.No.	Design Consistency	S.No.	Design Consistency	S.No.	Design Consistency
1	Poor	16	Fair	31	Fair
2	Poor	17	Fair	32	Poor
3	Good	18	Good	33	Fair
4	Poor	19	Poor	34	Poor
5	Poor	20	Poor	35	Fair
6	Poor	21	Fair	36	Poor
7	Poor	22	Fair	37	Poor
8	Poor	23	Good	38	Fair
9	Fair	24	Fair	39	Poor
10	Poor	25	Poor	40	Fair
11	Good	26	Poor	41	Poor
12	Poor	27	Poor	42	Fair
13	Fair	28	Good	43	Fair
14	Fair	29	Poor		
15	Poor	30	Good		

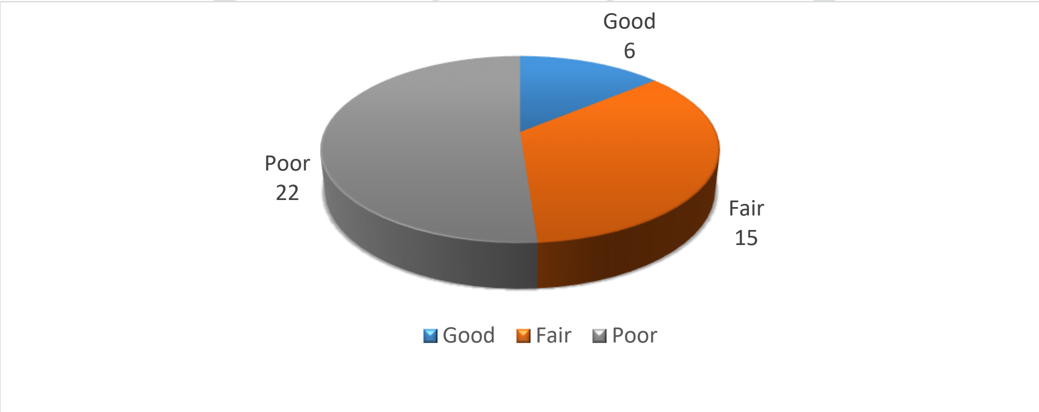

Figure 4. 2 Design Consistency Ratings for Light Vehicles Based on Criteria 2

From *Figure 4.2*, it was found that for light vehicles 6 horizontal curves had good consistency, 15 curves have fair consistency and 22 curves have poor consistency.

The design consistency evaluation of the studied horizontal curves for heavy vehicles on the basis of Criteria 2 is shown in *Table 4.3*.

Table 4. 3 Design Consistency Ratings for Heavy Vehicles for Criteria 2

S.No.	Design Consistency	S.No.	Design Consistency	S.No.	Design Consistency
1	Fair	16	Poor	31	Fair
2	Fair	17	Fair	32	Fair
3	Good	18	Good	33	Fair
4	Fair	19	Fair	34	Poor
5	Poor	20	Poor	35	Fair
6	Fair	21	Fair	36	Poor
7	Fair	22	Poor	37	Poor
8	Fair	23	Good	38	Poor
9	Fair	24	Fair	39	Fair

10	Poor	**25**	Poor	**40**	Fair
11	Good	**26**	Poor	**41**	Fair
12	Poor	**27**	Fair	**42**	Fair
13	Poor	**28**	Fair	**43**	Fair
14	Fair	**29**	Poor		
15	Poor	**30**	Good		

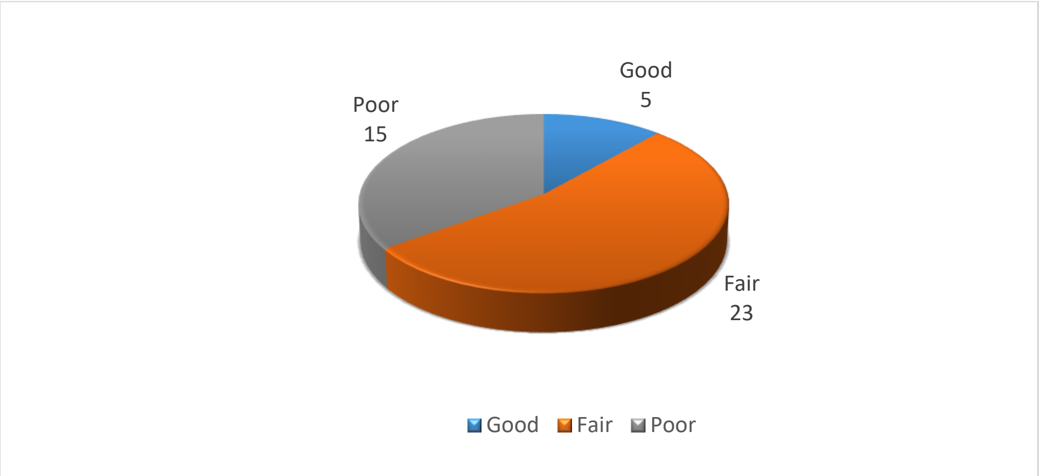

Figure 4. 3 Design Consistency Ratings for Heavy Vehicles Based on Criteria 2

From *Figure 4.3*, it was found that for light vehicles 5 horizontal curves had good consistency, 23 curves have fair consistency and 15 curves have poor consistency.

From above analysis, one can conclude that the horizontal curves used in this study are more inconsistent with respect to criteria 2.

5. Validation of Speed Prediction Models

The parameter used to validate models are mean absolute error (MAE) and mean absolute percent error (MAPE) which are calculated as

MAE= mean of |measured value – predicted value |

MAPE = mean of (|measured value – predicted value | ÷ predicted value *100)

Lower the values of above two for a linear regression model, higher is the accuracy of model in predicting the dependent variable.

Model 1

For this model the difference between predicted and measured speed ranged from -3.3 to 4.8 km/hr as shown in *Figure 8.1*. The mean of the absolute error (MAE) was 2.66 km/hr. The mean absolute percent error (MAPE) was 5.86 km/hr, which indicated that the prediction error was very low. See *Figure 5.2*.

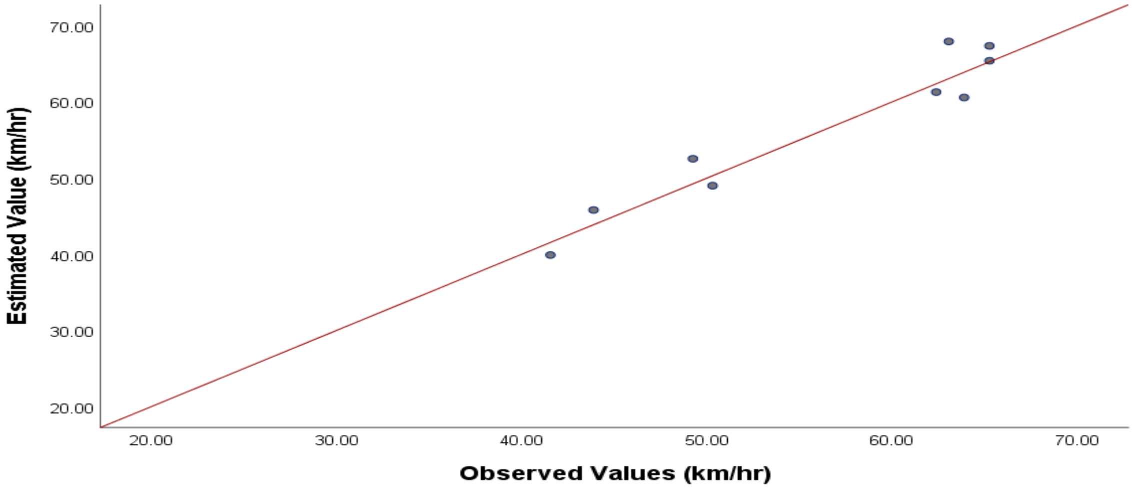

Figure 5. 1 Estimated versus Observed Values for Model 1

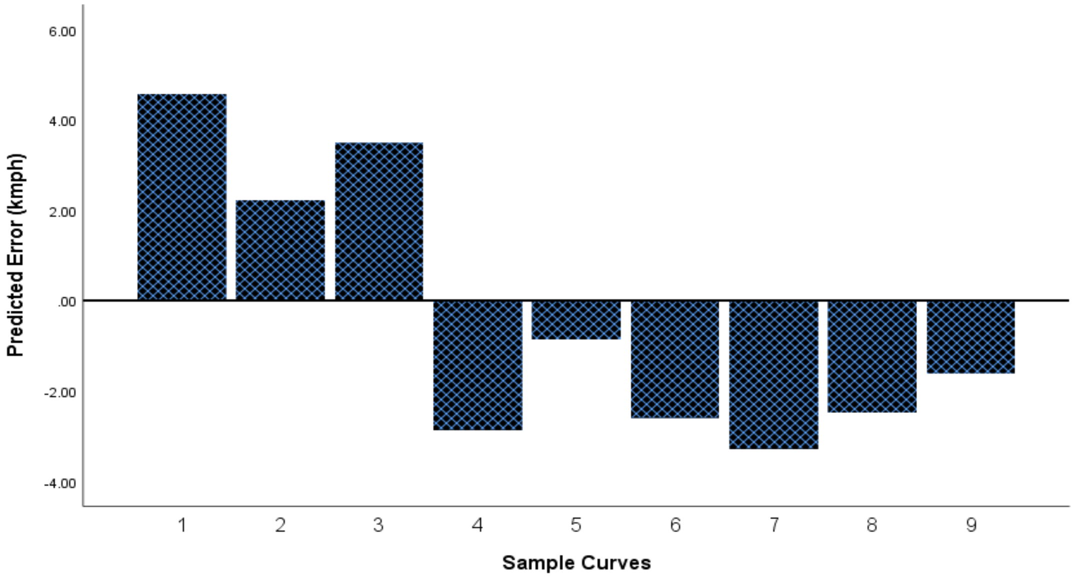

Figure 5. 2 Prediction Error for Validation Curves for Model 1

Model 2

For this model the difference between predicted and measured speed ranged from -3.6 to 4.7 km/hr as shown in *Figure 8.3*. The mean of the absolute error (MAE) was 2.07 km/hr. The mean absolute percent error (MAPE) was 4.31 km/hr, which indicated that the prediction error was very low. See *Figure 5.4*.

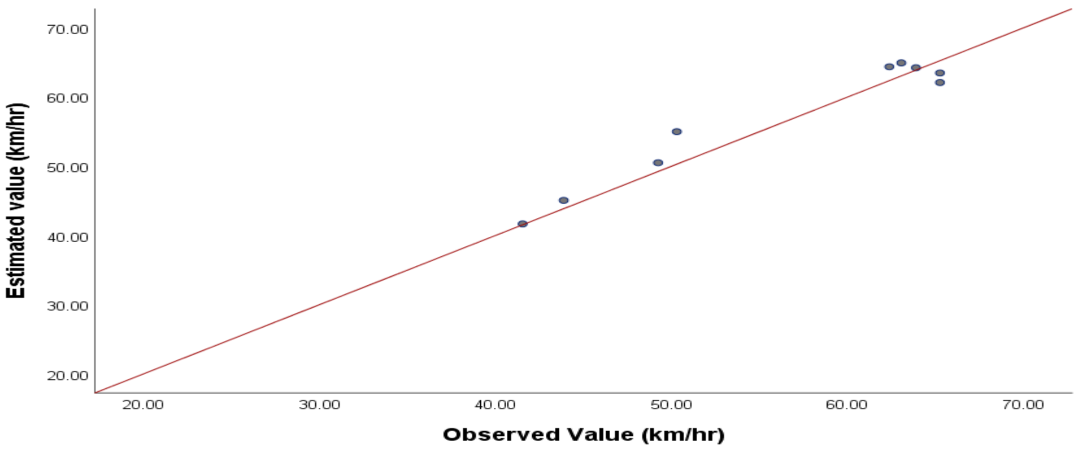

Figure 5. 3 Estimated versus Observed Values for Model 2

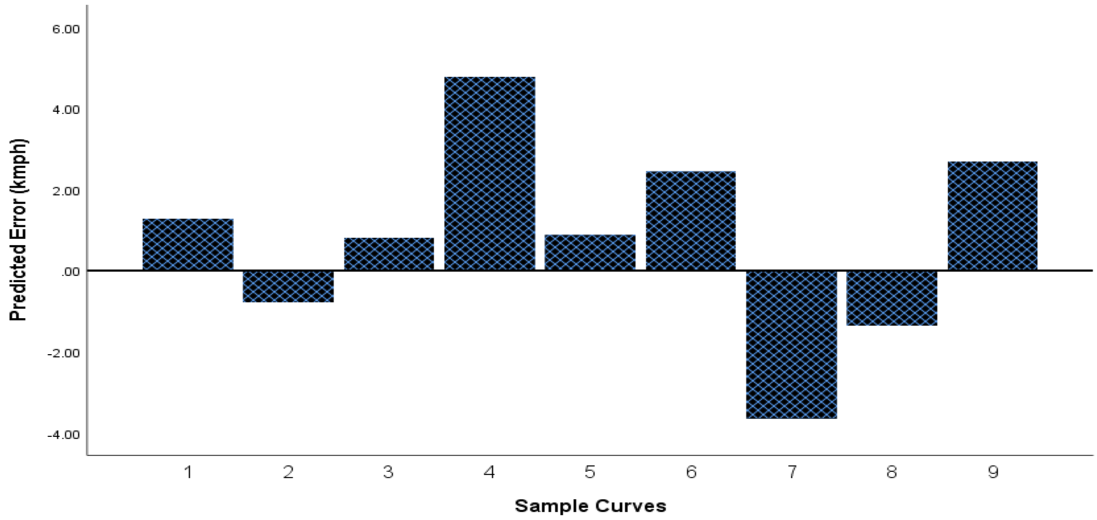

Figure 5. 4 Prediction Error for Validation Curves for Model 2

6. Conclusions

The following general conclusions were developed based upon the findings of the study:

1. Operating speeds for both light and heavy vehicles are same on inside and outside lane.
2. Operating speeds of cars and light passenger vehicles are not statistically different.
3. Operating speeds of light and heavy vehicles are significantly different.
4. Operating speeds of light vehicles is greater than heavy vehicles.
5. Out of 43 locations, 28 locations had good consistency, 13 locations had fair consistency and 2 locations had poor consistency for light vehicles based on criteria 1.
6. All the locations had good consistency for heavy vehicles based on criteria 1.
7. Out of all the locations examined in this study, 6 locations had good consistency, 15 locations had fair consistency and 22 locations had poor consistency for light vehicles based on criteria 2.
8. Out of all the locations examined in this study, 5 locations had good consistency, 23 locations had fair consistency and 15 locations had poor consistency for light vehicles based on criteria 2.
9. The radius of curve, deviation angle and preceding tangent speed are the main variables that influence drivers operating speed at the middle of the curve for both heavy and light vehicles.
10. The radius of curve and deviation angle are the main variables that influence drivers operating speed reduction from preceding tangent to the curve for both heavy and light vehicles.

7. References

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