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EXPLORING TANGENT-TO-CURVE SPEED DYNAMICS ON TWO-LANE ROADS IN NORTHERN NIGERIA

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ABSTRACT

The need for safer roads has given rise to exhaustive study of the road geometry and its interaction with other elements. Two-lane rural roads constitute the vast majority of the road network in many developing countries including Nigeria. Similar to inconsistencies in driving speed, it have been established that horizontal curve is also one of those areas were road safety can be improved. This study is aimed at investigating the relationship between speed characteristics of a tangent and the operating speed (V85) at the middle of the horizontal curve succeeding it. The average speed of traffic at the middle of the tangent was considered as the parameter of tangent speed characteristics. Super-elevation, radius and the gradient of the tangent under study were also used as independent variables in the model. Three models were developed with R^2-values of 0.532, 0.533 and 0.515 respectively. These R^2-values shows that more than 50% of the interaction is explained by the selected variables. It is concluded therefore, the speed characteristics of the preceding tangent can be used to explain the V85 at middle of the succeeding horizontal curve.

Keywords: Alignment, Horizontal curve, Operating speed, Regression, Road safety

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1. INTRODUCTION

Horizontal alignment is one of most important road features on the subject of traffic operation and safety. A typical horizontal alignment is made of series of tangents and fitted curves systematically arranged within a closed traverse. Traffic operation demands that these alignment elements be arranged in a certain order for safety and efficiency. It is estimated that nearly 60 per cent of highway fatalities occur on two-lane rural roads outside cities or towns and about half of these fatalities occur on curved roadway sections, as reported by [1]. Road safety research has consistently found that accident rates on horizontal curves are 3 to 5 times higher than the accidents rates on tangents sections of rural two-lane highways. This simply shows that by improving the accident prone sections such as curves and tangent-to-curve transition zones along the roadway, a lot of lives could be saved. This gain can be achieved by improving geometric design consistency thereby eliminating the possibility of sudden unexpected changes in driving conditions which often result to driver errors and consequently to accidents. The inconsistency of driving speed along successive alignment elements often lead to driving errors. This work will look into the dynamics of tangent-to-curve speed in relation to some selected traffic and alignment elements.

2. BACKGROUND

2.1. Operating Speed and Speed Profile

The use of speed profile to explain certain traffic behavior was adopted in the methodology of many studies. In most cases the focus is to determine the operating speed under different geometric conditions. Such conditions include the speed along vertical or horizontal curves, on transitions, along tangents and along combination of both vertical and horizontal alignments. Most works assumed design speed to be an important tool in design consistency evaluation and while the use of design speed is accepted by many countries, it is important to note that, design speed is the speed of a certain restricted element usually a horizontal curve chosen to represent the road including tangents where drivers can travel at higher speed, this in particular was identified to be one of the weakness of using design speed as consistency measure[2]. The speed behavior of drivers has is reported to be an excellent area for speed consistency evaluation. In the methodology adopted by [2] data obtained from over 200 sites on two-lane rural roads in the US was used to develop speed prediction models for different geometric conditions (vertical and horizontal alignment) in addition, the study also examined the effect of vehicle types and spiral curves on speed and further developed regression equations for passenger vehicle speeds on composition of vertical and horizontal alignment. In conclusion, the authors stated that, it’s not appropriate to consider speed variance as consistency measure for horizontal curves, and that there’s a strong relation between safety and reduction of speed by motorists on horizontal curve relative to a proceeding tangent or curve as also reported by [3]. Similarly, Anitha et.al [4] suggested that, the length of a tangent influence operating speed at the tangent succeeding it, length and radius also influence the operating speed at the middle of the first curve, while the operating speed at the middle of the second curve is according to the study influenced by the radius of first and second curve. The general point is the fact that the speed behavior on a certain alignment element can be affected by the characteristics of the one preceding or succeeding it.

2.2. Design Consistency

Design consistency requires the road to be forgiving of the driving errors by eliminating sudden alignment changes along the road. The forgiveness or explainability of road refers to the point when the driver and the driving environment are in harmony such that the frequency and effect of crashes are minimized. The need for self-explaining roads has been well supported by Burlacu et.al [5] who reported that about 30% of crashes in the European Union (EU) are said to be due to inadequacies in the infrastructural design and layout. The nature of the driving environment and the road geometry play an important role in driving along any given road. Highway design standards are in most cases expected to when correctly employed give safe and functional network of roads, yet accidents occur every day with fatalities and injuries recorded in progressing figures. Lamm et.al [1] state that if the design standards and guidelines assure the safety of the road and roads users, then **no** or **only very few** accidents should happen on that road. Lamm further argued that repeated accidents in a given section of a road shows a problem that has to do with the road and not the road users. In search for explanation to the issues similar to that raised by [1], several studies on design consistency were carried out based on Operating Speed, Vehicle Stability, Driver Workload or Alignment Indices as hinted by [3] out of the available methods mentioned, operating speed based method is the most effective and widely used due to the fact that speed is a visible indicator of consistency [6].

The very first stage of geometric design consistency evaluation based on the available models begins with estimating the operating speed, often defined as the 85th percentile speed (V_{85}) of vehicles recorded on a given road. Researchers from different part of the world have developed models for estimating operating speed of vehicles using various ranges of roadway features, characteristics of alignment among other suitable influencing variables.

Different consistency criterion were developed, such as those by Lamm et.al and that of J.C Glennon [3, 7, 8]. The criterion utilize Operating Speed as an important input. Operating Speed values for use in design consistency evaluation can be obtained from prediction models developed relevant to the section in question. One important aspect of Operating Speed Prediction Model formulation is the choice of the independent variable. The most commonly used variables are those related to speed (design speed and posted speed) and those related to the road alignment geometry (tangents, radius of horizontal curves, width, grade, superelevation). Other studies considered variables such as traffic, pavement condition and access density. In this work operating speed is used to explore the tangent-to-curve speed dynamics alongside other geometric variables.

3. THE PROJECT AREA

The project area is located within Kano and Katsina States in the northern part of Nigeria. Bordered by Cameroon and Chad to the east, Niger Republic to the north, Benin Republic to the west and the Atlantic Ocean to the south, Nigeria is a West African country covering about 923,768km2 of land. The predominant transport activities around the area is agro based throughout the year. The two selected roads covered a total length of about 230km combined. Record shows that these roads were initially constructed as low volume/speed track roads. The roads later underwent series of rehabilitation in term of surface riding quality but not much was done to improve the geometry. According to the Police record, the roads have a comparatively poor safety record.

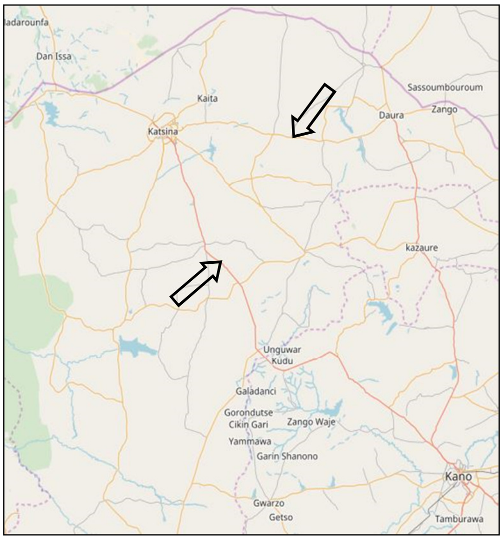

Figure 1 Map of the Project Area

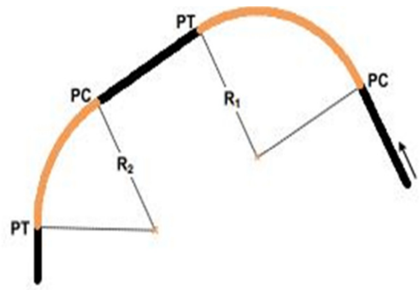

Figure 2 Horizontal curve showing PT & PC

4. DATA AND METHODS

The data was collected for all class of traffic excluding three and two wheelers under free flow condition. A total of fifty (50) curves and tangents were selected and surveyed. Speed measurement was done using hand held radar gun at middle of tangents and at the middle of horizontal curves. The position of the survey is hidden from the drivers' sight to minimize bias. An average number of 65 observations were recorded for each location. The mean speed, 50th percentile speed, and 85th percentile speed were evaluated accordingly. The operating speed (85th percentile speed) was defined in the modelling as dependent variable, super-elevation, radius, tangent length and average speed on tangent were used as independent variables. The alignment elements data was extracted from as built drawing of the roads, however, the values of super-elevation and grades where checked on site. To establish relationship between tangent speed characteristics and the operating speed at middle of a horizontal curve, a statistical analysis was carried out using SPSS23 package. A statistical summary of the data is shown in Tables 1. A typical set-up of the elements is shown in Figure 2. The figure shows site layout of successive tangents and curves. The observations are done at the middle of the tangent and the middle of the curve respectively

Table 1 Statistical Summary of Data

Variable	N	Minimum	Maximum	Mean	Std. Deviation
L1	50	45.22	12786.90	1621.70	2643.54
L2	50	31.48	12238.16	1975.91	2593.58
Radius m	50	396.94	3500.00	1069.64	594.70
Degree	50	4.65	64.25	24.13	14.56
Curve Length m	50	47.01	1115.35	389.01	217.67
SE %	50	0.42	12.78	3.24	1.91
Grad1	50	-2.19	5.27	0.42	1.20
Grad2	50	-1.70	5.22	0.32	1.12
AvMT	50	75.02	108.08	94.32	8.70
AvMC	50	75.70	106.66	90.22	6.66
50th MT	50	72.00	107.00	94.21	8.86

50th MC	50	76.00	109.50	89.81	7.50
85th MT	50	88.00	126.55	108.87	8.05
85th MC	50	83.50	121.00	104.61	8.41

- L1 & L2 are preceding and succeeding tangents respectively
- Degree means the degree of the curve
- S.E means super-elevation
- Grad1 & Grad2 are preceding and succeeding gradients respectively
- AVMT & AVMC are average speed at Mid-tangent and Mid-curve respectively
- 50^{th} & 85^{th} refers to 50^{th} percentile and 85^{th} percentile speeds respectively

5. RESULTS AND DISCUSSION

Three models were formulated as shown in Table 2. The average speed along the preceding tangent is used in all the three models. The first model in Equation 1 shows a positive relationship between the operating speed at the middle of the curve and the average speed at mid tangent. The same trend is maintained between the V85MC and radius of the curve. In all three models, super-elevation exhibited negative relationship with V85MC. This is in agreement with the general idea upon which S.E is introduced. Gradient of the preceding tangent (Grad1) and the radius inverse also exhibited a positive relationship with V85MC with weaker P-value. It is however fair to expect an increase in speed with a steeper downhill gradient. The R-square values of 0.532, 0.533 and 0.515 were obtained for the three models. This depicts that more than half of the V85MC is explained in relation to curve parameters and the characteristics of the preceding tangent. Table 2 gives the summary of the model parameters while the model equations are given in Equation 1 to 3.

Table 2 Summary of Model Parameters

times		**Unstandardized Coefficients**		**t**	**Sig.**	**R2**
		B	**Std. Error**			
$V_{85}MC$	(Constant)	53.482	9.712	5.507	.000	**0.532**
	SE %	-1.128	.450	-2.506	.016	
	AvMT	.544	.106	5.149	.000	
	Radius m	.003	.002	2.115	.040	
	(Constant)	52.884	9.958	5.311	.000	**0.533**
	Radius m	.003	.002	2.094	.042	
	SE %	-1.096	.465	-2.358	.023	
	AvMT	.545	.107	5.110	.000	
	Grad1	.272	.788	.345	.132	
	(Constant)	56.321	10.909	5.163	.000	**0.515**
	SE %	-.978	.474	-2.064	.045	
	AvMT	.578	.106	5.460	.000	
	Grad1	.199	.813	.245	.058	
	1/R	-2599.662	1633.55	-1.591	.062	

$$V85MC = 53.482 + 0.544AvMT + \frac{R}{300} - 1.13S.E.............................(1)$$

$$V85MC = 52.884 + 0.545AvMT + \frac{R}{300} + 0.272GRAD_1 - 1.1SE......(2)$$

$$V85MC = 56.321 + 0.578AvMT + 0.26GRAD_1 - \frac{2500}{R} - 0.9781SE.....(3)$$

5.1. Analysis of Variance and Residuals

The measure of variability within the model is given in Table 3. For all the three models the p-value was found to be <0.001. This shows that the variables are significant enough to give an important information about the dependent variable (V85M).

Table 3 ANOVA

Model	Aspect	Sum of Squares	df	Mean Square	F	P
1	Regression	1843.789	3	614.596	17.403	<0.001
	Residual	1624.532	46	35.316		
2	Regression	1848.073	4	462.018	12.832	<0.001
	Residual	1620.248	45	36.006		
3	Regression	1784.983	4	446.246	11.929	<0.001
	Residual	1683.338	45	37.408		

One of the basic assumption of the analysis method is that the residuals are normally distributed. It is therefore necessary to check whether this assumption is held within the final result. The errors are found to be normally distributed with zero mean and constant variance as presented in Figure 3. Similarly, the errors between the actual and predicted values are also found to be normally distributed as shown in Figure 4 & 5 for Model one. The residuals formed a horizontally dispersed band close to the zero line thereby justifying the regression assumption.

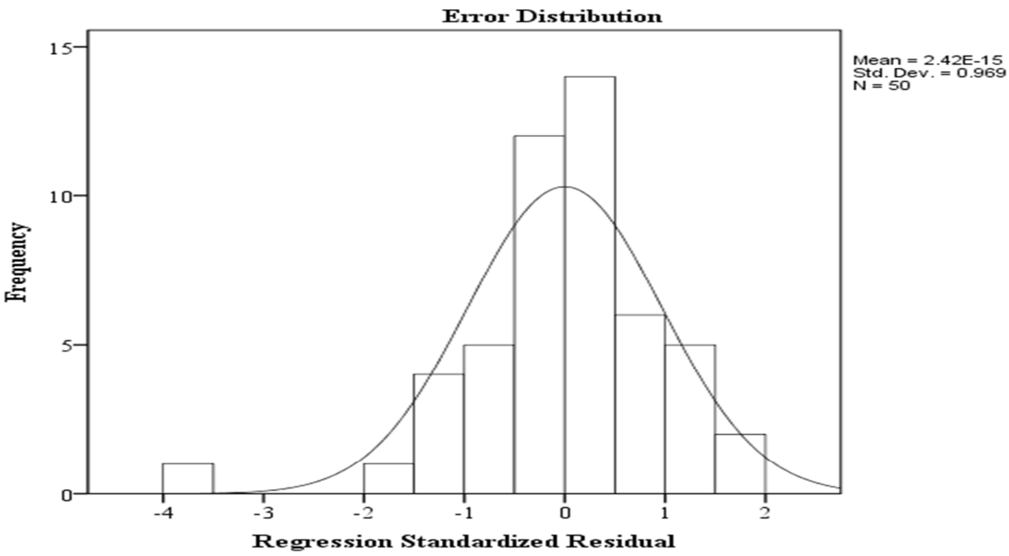

Figure 3 Error Distribution Histogram

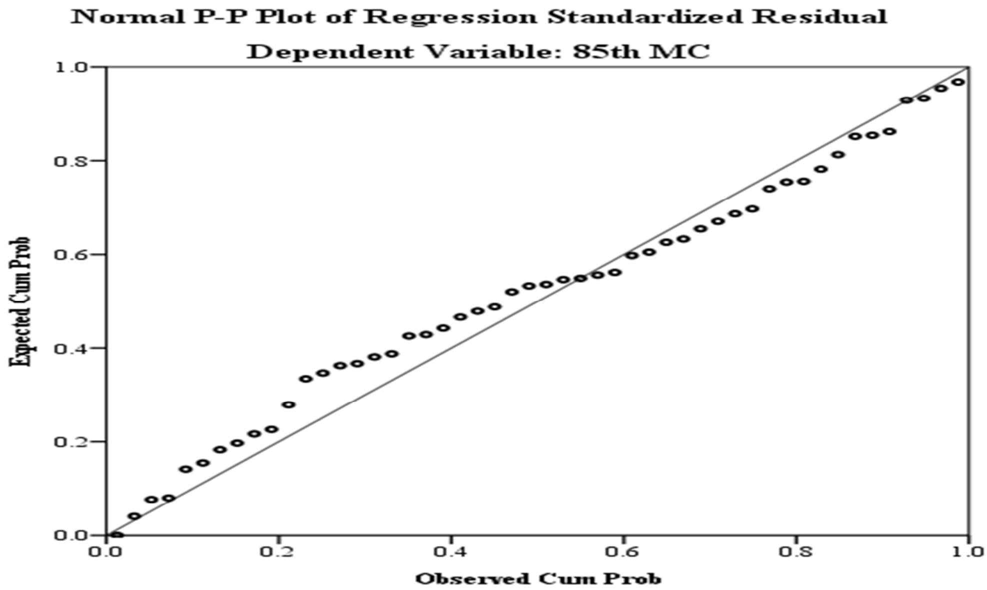

Figure 4 Residual Normal Probability Plot

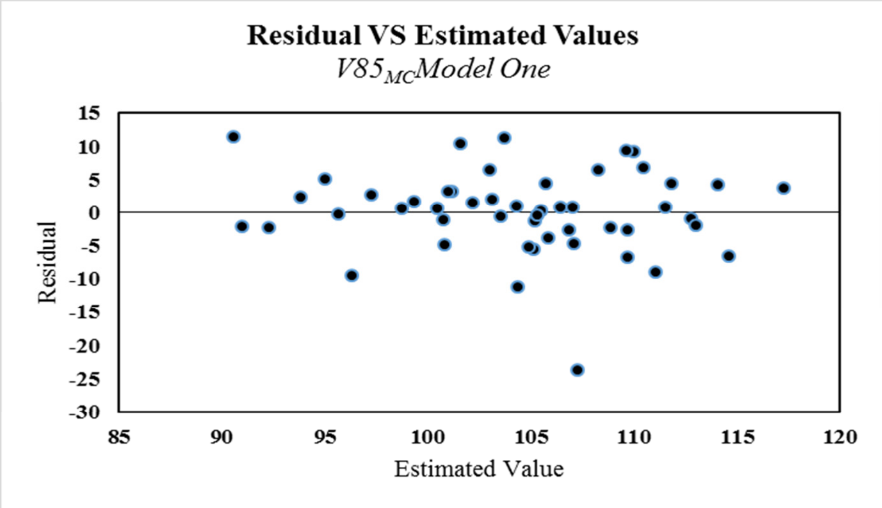

Figure 5 Residual Vs Estimated Values

6. CONCLUSION

In establishing the relationship between tangent speed characteristics and the operating speed the middle of horizontal curve most of the parameters were found to statistically significant at 95% confidence level. Therefore with the R-square value of more than 50% in each of the three cases, it can therefore be concluded that there is a mathematical connection between the speed parameters of the preceding tangent and the operating speed at the middle of the succeeding horizontal curve. The result from these models can be used as an additional option when carrying out geometry upgrade of a road and during road safety audits.

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