AN INVESTIGATION OF THE 85TH PERCENTILE OPERATING SPEED MODELS ON HORIZONTAL AND VERTICAL ALIGNMENTS FOR TWO-LANE RURAL HIGHWAYS: A CASE STUDY

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ABSTRACT

The number of accidents in Malaysia increases relatively from year to year, although there are many programmes organised by the authority to reduce them. There are several factors that lead to serious accident problems which are human behaviour, vehicle's condition, weather condition, road surface and road alignments (vertical and horizontal curves). This research paper presents an empirical research and presents design consistency models to estimate the 85th percentile operating speed models for the horizontal and vertical alignments at two-lane rural highways. The speed data were carried out by using a laser gun metre detector to obtain the spot speed data in the selected location along the Lenggong to Sauk two-lane rural highway in Perak. Multiple linear regression analysis was conducted to develop the 85th percentile speed models by combining the operating speed data and geometric elements data from different selected horizontal and vertical alignments. Finally, the horizontal and vertical alignment models have successfully developed in the paper. The findings are hoped to provide a starting point towards the national design standard for the highway designer and planner to improving the consistency geometric design elements of the two-lane rural highways.

Keywords: *Design Consistency, Horizontal Alignment, Operating Speed Model, Rural Highways, Vertical Alignment*

1.0 INTRODUCTION

A good quality road infrastructure means providing an appropriate level of mobility and land use access for drivers and pedestrians while maintaining a high degree of safety. Maintaining a high degree of safety for the movement of people and goods on the road should be emphasised in any road design [1, 2, 3, 4]. Geometric design can be referred to the selection of roadway elements that includes the horizontal alignment, vertical alignment, cross section and roadside of the highways or streets [5]. Many researches have applied several elements of the geometric design such as horizontal alignments and vertical alignments in other countries [4, 6, 7, 8, 9, 10, 11].

However, to date there has been no in-depth investigation reported on the model of the 85th percentile operating speed for horizontal and vertical alignments on the two-lane rural highways in Malaysia [5, 12]. This study is actually very important and crucial as there is a need to explore and develop a new model to enhance the existing guidelines and standards focussed on the horizontal and vertical alignments, especially for two-lane rural highways where high traffic speed is endured on the rural highways [1].

So far, the evaluation of the horizontal and vertical alignments' models are based on the relationship of operating speeds and other geometric elements [4, 6, 7, 8, 9, 10, 11]. Therefore, this study proposes models for evaluating the 85th percentile operating speed for horizontal and vertical alignments on the two-lane rural highways by developing operating speed models based on the local empirical data.

2.0 RESEARCH OBJECTIVES

The purpose of the study is to develop 85th percentile operating speed models that can be integrated in giving effects of highway geometry in horizontal and vertical alignments. The model can be used to estimate the operating speed of passenger vehicles. Subsequently, the parameters that are highly correlated between driver speed and geometric design elements can be justified based on R5 design standard and can assist the practitioners towards best practice in highway geometric design on two lane rural highways condition in the country.

3.0 LITERATURE REVIEW

3.1 Terminology

The definition of speed can take many forms and is one of the most important parameters in the geometric design of highway. The term 'speed' is a general term typically used to describe the actual speed of a group of vehicles over a certain section of roadway [9].

Speed is a fundamental factor in transportation engineering; it is often denoted by different terms while applied in different situations such as a design criterion, a measure of the level of service and as an operational control parameter [13].
A summary of the types of speed terminologies are presented in Table 1.

Table 1: Speed terminology

Type of Speed	Description	Source
Design Speed	As a speed selected to establish specific minimum geometric design elements for a particular section of highway. Other features such as widths of pavement and shoulders, horizontal and vertical alignment and etc. are generally related to design speed.	PWD; REAM [5, 12]
	A speed selected as a basis to establish appropriate geometric design elements for a particular section of road including horizontal and vertical alignment, super-elevation, sight distance, etc.	TAC [1]
	A design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, and functional classification of the highway; and, once selected, all the pertinent features of the highway should be related to the design speed.	AASHTO [14]
Operating Speed	The highest overall speed at which a driver can travel on a given road under favourable weather conditions and prevailing traffic conditions without at any time exceeding the design speed on a section by section basis.	PWD; REAM [5, 12]
	The speed selected by the highway users when not restricted by the other users (i.e. under free flow conditions).	Poe *et al.* [15]
	The speed at or below in which 85 percent of drivers are operating their vehicles.	Fitzpatrick *et al.* [16]
	The speed at which a driver is observed operating a vehicle (a 'spot' speed at a particular section). Reported as a mean or 85th percentile operating speed.	TAC [1]
	The speed at which drivers are observed operating their vehicles during free-flow conditions. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature.	AASHTO [14]
	The operating speed is the 85th percentile speed that drivers judge to be possible under prevailing traffic conditions on the road in question, but in the absence of cross-traffic.	Lay [17]
85th Percentile Speed	The 85th percentile operating speed is accepted as a safe speed in highway condition. Usually 15 percent of the drivers are considered as endangering and exceeding speed limit in the traffic flow, so these values become a criterion to fix the maximum speed limit and as a design value to carry out design works in highway geometric design.	Hamzah [18]
	The 85th percentile is used in evaluating or recommending posted speed limits based on the assumption that 85 percent of the drivers are travelling at speeds that are perceived to be safe. In others words, the 85th percentile operating speed is normally assumed to be the highest safe speed for a roadway section.	Homburger *et al.* [18]
	The distribution of observed speed is the most frequently used descriptive statistics for the operating speed associated with a particular location or geometric feature.	AASHTO [14]

3.2 Previous Work on Predicting Operating Speeds at Two-Lane Rural Highway

Previous research studies from the various regions and countries have developed an operating speed models prediction. In order to determine the operating speeds on the different types of geometric design elements, the operating speed prediction models from others researchers would be studied and reviewed. The purpose of reviewing these operating speed models is to discover the relationships between the operating speed and elements of geometric design. Several studies on the development of operating speed models focus on rural conditions. Operating speed prediction models have been developed for rural highways since 1950. Table 2 summarises the previous developed operating speed models for rural highway curves from other researchers.

Taragin [20] developed different curves for the various percentile speeds. The free-moving passenger car speeds were observed on the inside and outside lanes of 88 different curves on the two-lane highways in New York and Maryland. He investigated the coefficient of side friction, the effect of super-elevation, side distance and passenger-car speed based on the stopping sight distances. Taragin [20] found that super-elevation had no effect on speeds but the radius of curvature had a significant effect on speeds. He also concluded that sight distances should be at least 120 metres on the horizontal curves on the main rural highways if the drivers are to be expected to stop when an object suddenly appears in their lane.

Glennon *et al.* [21] studied the safety and operational characteristics of two-lane rural highway curves. Florida, Illinois, Michigan, Ohio, and Texas were selected as the case study and more than 1400 observations of vehicle speed behaviours were recorded at 60 curve approaches. The speed was recorded using motion pictures taken from the vehicles and vehicle traversals were analysed in the office using a 16 mm stop-action motion analyser. They identified the effects of the highway curvature (both degree and length), roadway width and transition design on driver behaviour. The research indicated important trade-offs among the curve radius, curve length and super-elevation. Hence, they concluded that the safety of highway curves can be improved by minimising the use of controls such as minimum radius for a given design speed and super-elevation of curvature, using spiral transitions, and avoiding large central angles.

Table 2: Summary of previous developed operating speed prediction models for rural highway curves

Author	Country	Year	Operating Speed Model	Data Collection	Sample Size	R-Sq
Taragin [20]	United States	1954	$V_{85} = 88.87 – 2554.76/R$	*n/a*	88(125)	0.86
Glennon *et al.* [21]	United States	1985	$V_{85} = 103.96 – 4524.94/R$	motion picture, following vehicles	60(~1400)	0.84
Lamm and Choueiri [22]	United States	1987	$V_{85} = 88.72 – 0.084CCR$ [LW=3.0m] $V_{85} = 89.55 – 2862.69/R$ [LW=3.0m] $V_{85} = 92.69 – 0.080CCR$ [LW=3.3m] $V_{85} = 93.83 – 2955.40/R$ [LW=3.3m] $V_{85} =95.77 – 0.076CCR$ [LW=3.6m] $V_{85} = 96.15 – 2803.70/R$ [LW=3.6m] $V_{85} = 94.39 – 3188.57/R = 93.85 – 0.045CCR$ $V_{85} = 55.84 – 2809.32/R + 0.634LW + 0.053SW + 0.0004AADT$	stop watch	261(*n/a*)	0.85 0.75 0.73 0.75 0.84 0.82 0.79 0.84
McFadden and Elefteriadou [7]	United States	1997	$V_{85} = 41.62 – 1.29D + 0.0049L_C – 12\Delta + 0.95V_{85AT}$ $V_{85} = 106.3 – 3595.29/R$	*n/a*	78(*n/a*)	0.90 0.92
Andueza [23]	United States	2000	$V_{85} = 98.25 – 2795 / R – 894 / R_a + 7.486DC + 9.308L_T$ [for HC] $V_{85} = 100.69 – 3032 / R + 27.819L_T$ [Tangent]	radar gun	78(30~64)	0.84 0.85
Geometric Design Guide for Canadian Roads [1]	Canada	1999	$V_{85} = 102.45 + 0.0037L_C – (8995 + 5.73L_C)/R$	*n/a*	*n/a*	*n/a*
Misaghi [24]	Canada	2003	$V_{85AT} = – 97.19 + 52.32LW + 18.26(drv\_flag) + 0.0018Ra – 1.47SW$ $V_{85MC} = 101.4 – 4900053 / R^2$	radar gun, counter / classifier	16(24h)	0.97 0.51
Gonet [25]	Ethiopia	2007	$V_{85} = 147.88 – 7.162G – 2.990e$ [for HC] $V_{85} = 127.3 – 4.461G$ [for Tangent]	radar gun	43(*n/a*)	0.57 0.59
Memon *et al.* [4]	Pakistan	2008	$V_{85MC} = 40.4 – 1571/R + 0.613MaxV_{85T} + 0.0244L_C – 0.163I$ $MaxV_{85T} = 111 + 0.0110L_T – 2757/R_1 – 1225/R_2$	global position system	11(232)	0.84 0.62
Cardoso *et al.* [26]	Brazil	2010	$V_{85} = (10^6) / (10.238 + 59754CCR)$ $V_{85} = (10^6) / (9.6722 + 64135CCR)$	counter / classifier	16(100)	0.81 0.82

Note: Sample size is the number of sites and number of observations per site respectively.
n/a = information was not provided.
A description of the symbols is in the Nomenclature at page 39.

Lamm and Choueiri [22] developed several models on 261 two-lane rural highway sections in New York State. They suggested the lane width, shoulder width, radius of curve, degree of curvature and average annual daily traffic as the most convenient for predicting the operating speed along rural highways. Therefore, the highway engineer could control minor inconsistencies in the highway alignment, and detect the major geometric defects.

Furthermore, McFadden and Elefteriadou [7] used two back propagation artificial neural network models to validate and formulate the speed profile using the same dataset collected by Krammes *et al.* [27]. About two third of the data site were used for network training and the remaining were used for model validation. It was concluded that, the comparison found that McFadden and Elefteriadou [7] offered predictive powers comparable to the models used by Krammes *et al.* [27].

Andueza [23] explored the vehicular speed on the curve and tangent sections of the Venezuelan Andean highway in Venezuela at the mountainous road areas. Spot speeds studies were conducted with a radar gun at the middle of 42 curves and 36 tangents. The 85th percentile operating speed and the average speed were estimated using the radius of the previous curve and tangent length. The study concluded that, speed and comfort were two measured efficiencies for drivers on the curves. In addition, on some curves, a certain degree of discomfort exchange was preferred to obtained greater speeds.

The Canadian Design Guidelines [1] proposed the design consistency to predict the operating speeds with different geometric elements. The prediction models were based on the collected data from five US states under free-flow traffic conditions on long tangents (250 metres and more) and on horizontal curves on two-lane rural highways.

It was found that the mean 85th percentile speed on long tangents was about 99.8 km/h for a level terrain and 96.6 km/h for a rolling terrain. At the horizontal curve radius, it was found that there were greater disparities between the 85th percentile speed and radius curves. The 85th percentile speed exceeded the design speed with the 10 km/h increment in 100 km/h of design speed. Hence, with the higher design speeds, the 85th percentile speed was lower than the design speed.

Misaghi [24] found that some of the models had no relationship between speed at the middle of the curves and the geometric features of the horizontal curves at the 95% confidence level. Furthermore, there was no significant difference between the speed at the approach tangent and the geometric features of the section. Therefore, they recommended the values of 103.0 km/h and 95.7 km/h as a value of the observed 85th percentile speed at the dependent and independent tangents respectively.

Gonet [25] investigated that the consistency of a design was to evaluate changes in the operating speeds along an alignment. He focused on evaluating the geometric design consistency of the selected alignments and in developing the 85th percentile operating speed predicting models for the selected sections. The speed of the passenger cars, buses, and trucks was measured on each curve and its approaching tangent at five trunk roads in Addis Ababa, Ethiopia during dry daytime conditions. On these five trunk roads, 43 simple horizontal curve sections were selected in which the operating speeds were measured using a radar gun. He found that grade and super-elevation were significant variables in the regression equations developed for the operating speeds of motorists on the horizontal curves of two- lane rural highways.

Memon *et al.* [4] studied the operating speed models for two-lane rural roads in Pakistan. The study used continuous speed profile data collected at 11 test sites at Sindh and Balochistan, Pakistan's two-lane rural roads. Data were collected using a GPS based device in both directions of traffic flow. Two different methods, which were the test driver method and car following method, were used in the study. For each method, approximately 30 selected test drivers were directed to drive the test vehicle along the test section and approximately 30 passenger vehicles were randomly followed along every test section. The development and validation of the models on horizontal curves and on tangents were evaluated for design consistency. Based on the collected continuous speed data, Memon *et al.* [4] concluded that the model developed for the operating speed on the horizontal curve indicated a strong correlation to the maximum 85th percentile approach the tangent speed and the radius of the curve. Furthermore, the model for predicting the tangent speed was also highly related to the preceding and succeeding curves and length of the tangent. From the validation results, the developed models showed the compatibility with the trend of the experimental data, and greater variation was also found between the developed model and the models developed in various countries.

Recently, Cardoso *et al.* [26] conducted a study on the design consistency on two-lane rural highways. The objective of the study was to develop a speed-prediction model for two-lane rural highways in Brazil, especially Highways in the State of São Paulo. A minimum of 100 observation speeds of each site was collected using a portable Nu-Metrics counter, model NC-97, which worked with a magnetic sensor. The value of the curve radius, super-elevation, grade, slope and speed on 14 curves and 1 tangent were studied.

They found that the curves with a radius of curvature larger than 100 metres were similar to those predicted by the equation in the study of Fitzpatrick *et al.* [9]. However, when the radius of curvature was shorter than 100 metres, the observed speeds were closer to the equation elaborated by Lamm *et al.* [28].

The following are the summary of the findings of the previous related studies:

1. The use of 85th percentile operating speed to be included into the model development is generally accepted as a measure of the operating speed at specific locations. Most of the studies used the 85th percentile speed as a variable to show a relationship with the other geometric design elements. By using the 85th percentile speed as a representative measure for the operating speed, the studies attempted to identify the operating speed threshold under which 85 percent of the drivers travelled.
2. The previous studies used statistical methods such as simple linear regression, multiple linear regressions, stepwise regression analysis, logistic regression analysis, bivariate and multivariate analyses, ordinary least squares and artificial neural network. All the studies provided the proportion of variability in a data set like R^2 or R^2adj; however, the quality of the prediction or in-depth of analysis (correlation analysis, analysis of variance, significant p-value, validity model check, etc.), in the statistical analysis was not shown in their studies.
3. Limited study to date exists on separated vertical alignment for two-lane rural highways. The reason might be both the vertical curves have combined with the horizontal alignments.
4. Very few studies focus on the operating speed models on tangents especially on the horizontal curves. The possible reason might be that on the tangent section, there are no geometric element constraints on the driver's speed. At the horizontal curve, the operating speed constraints with the length of the approach tangents, radius of curve or length of curve.
5. Most of the existing operating speed models are point speed at specific locations such as approach and departure tangents (AT/DT), beginning, middle and end of circular part of the curve (BC,MC, and EC respectively). Those point speed models are based on assumptions such as the following such as drivers reach their lowest speed at the mid-point of curves and drivers reach their highest speed at the approach tangent section.

Based on the summary above, the study will measures the operating speed at the specific point locations and used the 85th percentile operating speed in the model development. The 85th percentile operating speed models will develop using multiple linear regressions analysis. The in-depth of analysis on proposed models will consider in this paper. Moreover, the paper will focus on horizontal and vertical alignments independently. In addition, at horizontal alignment, the study also focuses on the operating speed on approach tangents lane especially on the horizontal curves.

4.0 RESEARCH METHODOLOGY

The research flowchart, which focuses on the operating speed models for horizontal and vertical curves as shown in Figure 1.

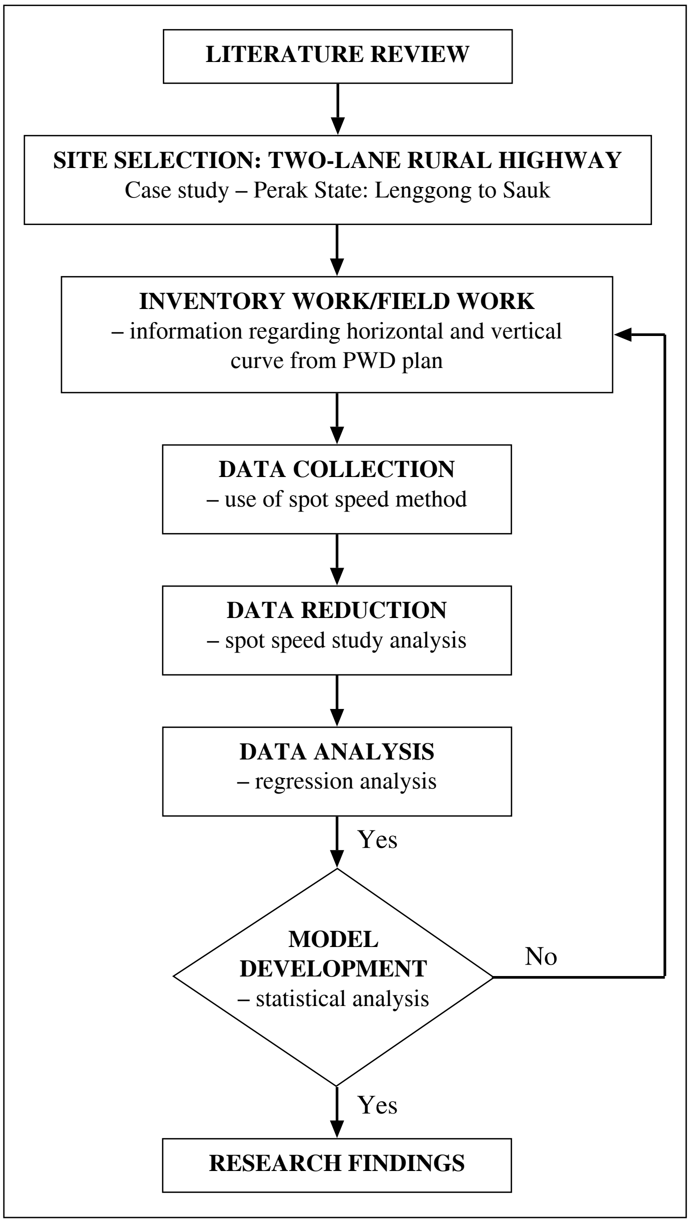

Figure 1: Flowchart of research process

At this field study, the operating speed at the horizontal and vertical curves was collected using a laser gun metre detector while a roller metre was used for measuring the length of every curve. The study areas had geometric data information such as rate of vertical curve, length of curves, radius of curves and other elements in the construction drawing plan obtained from the Public Works Department [29]. The data collection at site involved observation and recorded operating speeds of the vehicles. The data collected were recorded in the proper data form to facilitate further analysis. The 85th percentile speed was calculated using the analysis of spot speed data method. The 85th percentile operating speed data and design geometric elements data were transferred to statistical software package, Minitab version 16.0 to develop a model that would represent the speed characteristics for the selected curves.

4.1 Site Selection

Malaysia has different categories of highways road design. In Arahan Teknik (Jalan) 8/86 [12], the design standard is classified into seven groups denoted as R6, R5, R4, R3, R2, R1 and R1a for rural areas and into seven groups denoted as U6, U5, U4, U3, U2, U1, and U1a for urban areas. These are in descending order of hierarchy. Roads which function to provide long distance travel, will require higher, design speeds whilst roads which serve local traffic, where the effect of speed is less significant can have a lower design speed. Futhermore, roads with heavier traffic will be provided with a higher standard. The site selected for the case study areas is in Perak State: Lenggong to Sauk two-lane rural highways as shown in Figure 2, which has high accident problem. The study area has criteria such as the classification of road is R5 Standard, which means in REAM [5] guidelines that provide high geometric standards and usually serve long to intermediate trip lengths with high to medium travelling speeds. The design speed on that area is 100 km/h and the posted speed on that area is 80 km/h. The speed data were collected for all types of vehicles in traffic stream under free flow conditions. The vertical and horizontal sites were selected with the following criteria; (i) no intersection being along this site; (ii) no physical features that cause an obstruction of operating speed such as speed reducer, or traffic light system along the site; (iii) the road must be in good dry condition because in wet or rainy condition can cause the operating speed to become slow.

Figure 2: The case study area at Perak two-lane rural highway, horizontal and vertical curves

4.2 Inventory Work (Geometrical Data)

The study areas have geometric information in the construction drawing plan obtained from the Public Works Department of Malaysia [30]. For the horizontal curve, the data included the radius of simple circular curve (RC), length of simple circular curve (LC), length of tangent (LT), station of the beginning of the curve (PC), the point of intersection (PI) and the end of the curve (PT). While for the vertical curve, the geometric data included the rate of the vertical curve (K), gradient of the curve (G), length of the vertical curve (VCL), the point of the beginning of the curve (VPC), the point of intersection (VPI), and the end of the curve (VPT). However, some of the geometric design elements data can be extracted from the original construction plan. The pavement lane and unpaved shoulder width were measured to fulfil the requirements of the R5 design standard [5] in which the pavement lane is 3.5 metres and the unpaved shoulder is 0.2 metre.

4.3 Data Collection

The horizontal alignment of a road consists of the simple circular curves. These types of curves are usually a part of the segments of circles which have the radius and approach tangents line that provide a smooth flow of traffic along the curve. The curve may not be accompanied by a transition section. Apart from that, the vertical alignments of the road consist of tangent grades in sag and crest vertical curves.

The data collection at the site involves observing the operating speed and recording the speeds of the vehicles. The speeds were collected from three vehicle types: passenger cars, buses and trucks. The speed data were collected at every 15 minutes interval at least in one hour at every selected curve.

The operating speed of the different types of vehicles was collected by observing the operating speed value using a laser gun metre detector. The data collected were recorded in the spot speed data form to facilitate further analysis. The observations of speed were recorded at three points along the horizontal and vertical curves respectively, which were before or approach tangent of the curve, at the middle of curve, and at the end point of the curve. The summary of the available geometric design data of the test sections is presented in Table 3.

Table 3: Detail of selected section

Data	Horizontal	Vertical
Number of Curves	6	6
Radius of Horizontal Curve, RC (m)	700 to 2000	–
Rate of Vertical Curve, K (%/m)	–	30 to 110
Length of Curve, L_C/VCL (m)	55 to 600	200 to 400
Gradient, G (%)	–	–6 to +6
Length of Tangent, L_T (m)	300 to 1200	–

4.4 Data Reduction

The major tasks of this study were the data collection and reduction of field data to be used in the development of the operating speed models. These data included the operating speed data and geometrical elements data at the selected areas. The geometric element data from the data collection form were entered into the spread sheet system filling. In order to achieve the objectives, data from twelve sites were used for further analysis in the multiple linear regression analysis. These twelve different sites were carried out for the operating speed observation with different geometric elements of horizontal and vertical curves, while the geometric design elements data such as the length of the approach tangent, length of curve, radius of curve, gradient of curve and the rate of vertical curve at the selected curve section were carefully investigated.

The data collected in spot speed studies were usually taken only from random vehicles at the selected area in which the study was conducted. These data were used to determine the speed characteristics of the vehicles travelling on the selected area. Therefore, it was necessary to obtaining the 85th percentile speed [2]. The multiple linear regression analysis was performed by using the Minitab v16.0 [30] a statistical software package to develop a model that would represent the speed characteristics for the selected curves.

5.0 DATA ANALYSIS AND MODEL DEVELOPMENT

The data analysis and model development started with the presenting the descriptive statistics for the dependent and independent variables after removing the outliers. The next procedure was to determine the correlation analysis to measure the degree of the linear relationship between two variables.

From the correlation analysis, the process was followed by the identification of the independent variables with the response variables. A series of multiple linear regressions was applied to the data to identify the best combination and relationship of the variable to predict the horizontal and vertical curve models with Minitab v16.0. The p-value and coefficient of determination, R^2 would be used to select the candidate variable. The models with a higher R^2 and a p-value is significant ($p < 0.05$) could be selected in the model development. Then, the validity of the final models in this study was checked using the Anderson Darling and Kolmogorov Smirnov normality test.

5.1 Descriptive Statistics for Horizontal and Vertical Curve

The summary of the mean, standard error mean, standard deviation, minimum value, median, maximum value, skewness and kurtosis after the identification and removal of the outlier for horizontal and vertical curve as shown in Table 4 (page 37).

In short, skewness and kurtosis shows how the distribution of a variable deviates from a normal distribution. A normally distributed sample has a skewness and kurtosis value of zero [31]. Overall, the values of skewness and kurtosis in Table 4 are near to zero, which means the data in general is normally distributed.

5.2 Correlation Analysis for Horizontal and Vertical Curve

The correlations analyses for horizontal and vertical curve are shown in Table 5 (page 37). The hypothesis for the correlation analysis test can be stated as follows:

H_0 = There no correlation between two variables

H_1 = There is correlation between two variables

Table 5 displays the correlations for the lower triangle of the correlation matrix when there are more than two variables. The results of the correlation analysis showed that all the variables was significantly correlated others because the p-value less than α value (0.05), hence the H_0 was rejected and accepted the H_1. Hence, these variables are significant correlated.

5.3 Interpretation of Horizontal Curve Model (V_{85HMC}) and Vertical Curve Model (V_{85VBC})

The V_{85HMC} horizontal curve model includes variables such as V_{85HAT} and RC as the predictors. In this study, the variable RC had been transformed using normalisation to follow a normal distribution. While, the V_{85VBC} vertical curve model includes variables such as V_{85VMC} and K as the predictors. The variable K also had been transformed using normalisation to follow a normal distribution. Table 6 shows a constant value, the inverse of radius of curves squared (1/RC), the 85th percentile operating speed at the approach tangent of the horizontal curves (V_{85HAT}), the inverse of rate of vertical curve and (1/K) and the 85th percentile operating speed at the middle of the vertical curves (V_{85HAT}). The hypothesis for the final models for estimating V85HMC and V85VBC model can be stated as follows:

H_0 = The predictor cannot be used for predicting in both models.

H_1 = The predictor can be used for predicting in both models.

From Table 5, V_{85HAT}, 1/RC for horizontal curve, and V_{85VMC}, 1/K for vertical curve which are significant independent variables for predicting V_{85HMC} and V_{85VBC} respectively where the p-value is less than 0.05, meaning that the H_0 is rejected and accept the H_1. Hence, these predictors can be included in the model for estimating both models.

Table 4: Descriptive statistics after removing the outliers for the horizontal and vertical curve

Variable	Mean	S.E Mean	StDev.	Min.	Median	Max.	Skewness	Kurtosis
V_{85HAT}	100.11	0.656	6.66	84.7	99.45	113.70	-0.12	-0.28
V_{85HMC}	95.286	0.655	6.643	79.7	94.95	112.95	0.27	-0.11
RC	1176.7	47.6	483.3	700	800	2000	0.52	-1.28
V_{85VBC}	100.49	0.887	8.96	73.83	101.37	117.20	-0.94	0.98
V_{85VMC}	98.246	0.839	8.475	76.075	98.575	116.825	-0.24	-0.36
K	48.78	1.62	16.33	30.15	49.75	74.35	0.28	-1.23

Table 5: The correlation matrix for the horizontal and vertical curve

		V_{85HAT}	**V_{85HMC}**			**V_{85VBC}**	**V_{85VMC}**
HORIZONTAL	**V_{85HMC}**	0.757	–	**VERTICAL**	**V_{85VMC}**	0.697	–
		0.000	–			0.000	–
	RC	0.457	0.473		**K**	-0.624	-0.369
		0.000	0.000			0.000	0.000

*Cell Contents
Pearson Correlation
p-value

Table 6: Regression analysis for final models for estimating V_{85HMC} and V_{85VBC}

Predictor	Coefficient	Standard Error Coefficient	T - value	p - value	R-Sq
Constant	31.204	7.587	4.11	0.000	
V_{85HAT}	0.67465	0.06946	9.71	0.000	60.2%
1/RC	-3479	1272	-2.74	0.007	
Constant	30.222	6.443	4.69	0.000	
V_{85VMC}	0.60161	0.06747	8.92	0.000	62.2%
1/K	485.26	73.32	6.62	0.000	

5.4 Analysis of Variance Test for V_{85HMC} and V_{85VBC} Model

The analysis of variance (ANOVA) portion of the output is as shown in Table 7. The hypothesis for the ANOVA test can be stated as:

H_0 = Both cannot be used for predicting.

H_1 = Both model can be used for predicting.

From Table 7, the p-value for both models less than the α-level of 0.05, thus decide to reject the H_0 and accept the H_1. Hence, the regression models are significant and thus can be used to explain or predict the V_{85HMC} and V_{85VBC} model.

Table 7: Analysis of variance for final model V_{85HMC} and V_{85VBC} model

Model	Source	DF	SS	MS	F-test	p-value
V_{85HMC}	**Regression**	2	2711.1	1355.6	75.71	0.000
	Residual Error	100	1790.4	17.9	–	–
	Total	102	4501.6	–	–	–
V_{85VBC}	**Regression**	2	5042.7	2521.3	81.40	0.000
	Residual Error	99	3066.6	31.0	–	–
	Total	101	8109.3	–	–	–

In conclusion, the equations on predicting the 85th percentile operating speed at the middle of the horizontal curve (V_{85HMC}) and 85th percentile operating speed at before of the vertical curve (V_{85VBC}) have developed as shown in equation 1.1 and 1.2 respectively:

$$V_{85HMC} = 0.675V_{85HAT} - \frac{3479}{RC} + 31.2 \quad (1)$$

$$V_{85VBC} = 0.602V_{85VMC} + \frac{485}{K} + 30.2 \quad (2)$$

Where;

V_{85HMC} = 85th percentile speed at middle of horizontal curve (km/h)
V_{85HAT} = 85th percentile speed at approach tangent of horizontal curve (km/h)
RC = radius of horizontal curve (m)
V_{85VBC} = 85th percentile speed at before of vertical curve (km/h)
V_{85VMC} = 85th percentile speed at middle of vertical curve (km/h)
K = rate of vertical curve (%/m)

The equation 1 shows that the coefficient for the predictor variable RC has a negative sign, implying that an increase in the RC value will lead to a decrease in the 85th percentile speed at the middle of the horizontal curve (V_{85HMC}). While the equation 2 shows that the coefficient for the predictor variable K has a positive sign, implying that an increase in the K value will lead to an increase in the 85th percentile speed at the before of the vertical curve (V_{85VBC}).

5.5 Justification of the Regression Model Assumptions

The residual plots are the difference between the observed response value and the fitted response value. Figures 3 and 4 show the residuals versus fitted values plot for V_{85HMC} and V_{85VBC} models respectively. From the figures, the points in the residual plots are scattered randomly at about zero. Therefore, no evidence of non-constant variance, missing terms, or outliers exists [30].

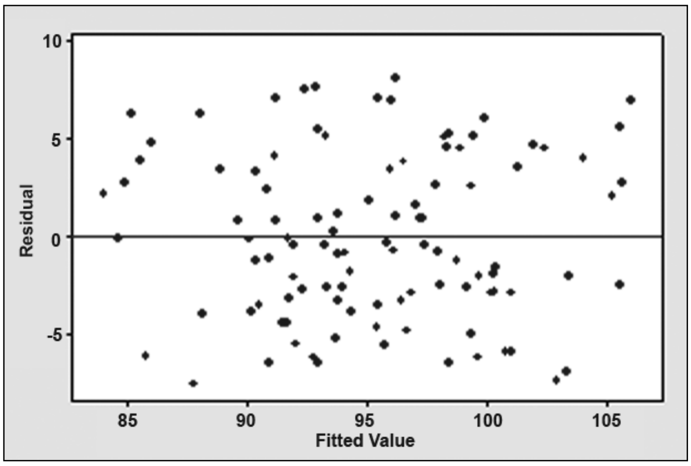

Figure 3: Residual versus fitted values for V_{85HMC} model

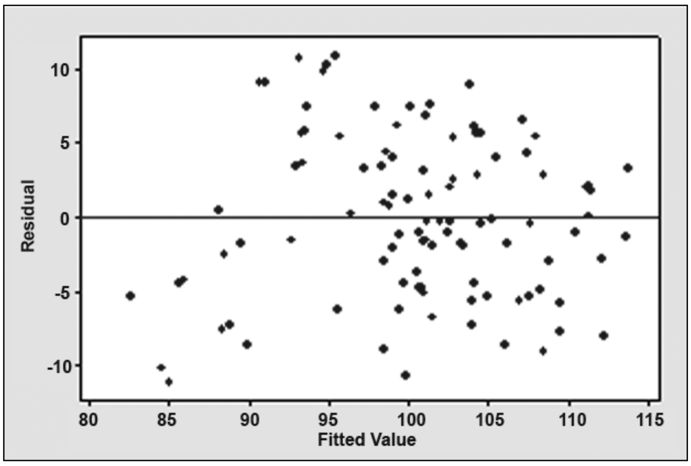

Figure 4: Residual versus fitted values for V_{85VBC} model

5.6 Normality Testing for Residuals

The use the probability plot and goodness-of-fit tests, such as the Anderson-Darling and Kolmogorov Smirnov normality test, is to assess whether the residuals are normally distributed. As can be seen in Figures 5 and 6 the points are scattered closely around the straight line which means the residuals are normally distributed [30].

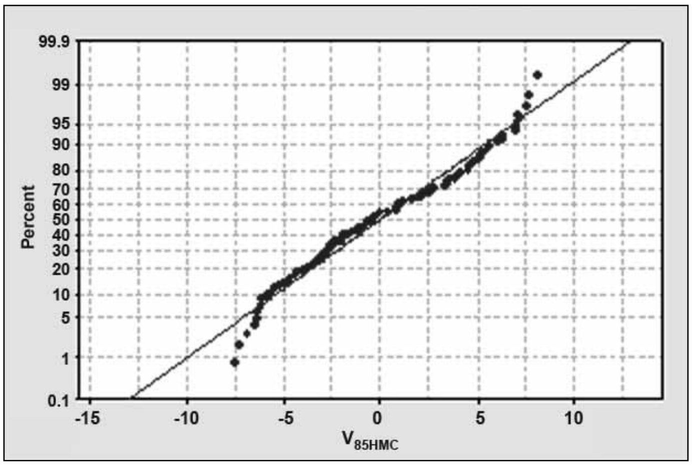

Figure 5: Normal probability plot of residual for V_{85HMC} model

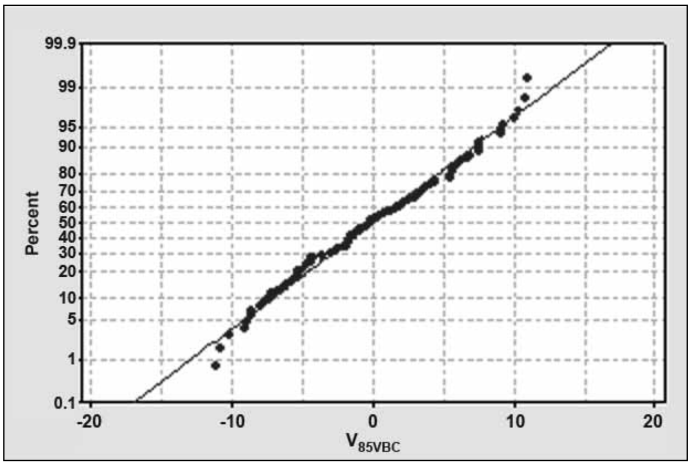

Figure 6: Normal probability plot of residual for V_{85VBC} model

The hypothesis test for the Anderson-Darling and Kolmogorov Smirnov normality test can be stated as follows:

H_0 = The residuals for the predicted model is normal.

H_1 = The residuals for the predicted model is not normal.

By referring to Table 8, since all the p-values of the Anderson-Darling and Kolmogorov Smirnov normality tests are more than 0.05, H_0 is not rejected and the null hypothesis (H_0) is accepted, and hence the residuals for the two models follow a normal distribution curve.

Table 8: Statistical normality results

Statistical Test	p-value	
	V_{85HMC}	V_{85VBC}
Anderson Darling	0.210	0.342
Kolmogorov Smirnov	>0.150	>0.150

6.0 CONCLUSION

The 85th percentile operating speed at middle of horizontal curve (V_{85HMC}) and 85th percentile operating speed at before of vertical curve (V_{85VBC}) models for Malaysian rural highway traffic have been successfully developed in this study. These models highlight importance in various aspects of operating speed on rural highway and geometric design elements of horizontal and vertical alignment. It was found that, RC, V_{85HAT} for horizontal alignment and K, V_{85VMC} for vertical alignment shows the statistically significant predictors of the V_{85HMC} and V_{85VBC} models respectively. However, the models developed must be evaluated to check its ability to represent actual condition. The findings are hoped to provide a starting point towards the national design standard for the highway designer and planner to improving the consistency geometric design elements of the highway.

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NOMENCLATURE

CCR	Curvature change rate (degree/km)
D; DC	Degree of curvature (degrees)
Δ	Deflection angle (degrees)
drv-flag	Driveway flag (intersection on curve: drv-flag=1; otherwise: drv-flag=0)
e	Rate of super-elevation (%)
G	Vertical grade (%)
HC	Horizontal curve
HT	Horizontal tangent
I	Longitudinal grade (%)
K	Rate of vertical curve for 1% change in grade (m); A / (L_V;VCL)
L_C	Length of horizontal circular curve (m)
L_T	Length of tangent (m)
L_V;VCL	Length of vertical curve (m)
LW	Lane width (m)
MaxV_{85T}	Maximum 85th percentile speed on approach tangent (km/h)
R; RC	Radius of the curve (m)
R_1	Radius of curve 1 of the compound curve (m)
R_2	Radius of curve 2 of the compound curve (m)
Ra	Radius of previous/preceding curve (m)
Rb	Radius of next/succeeding curve (m)
SW	Shoulder width (m)
V_{85}	85th percentile speed (km/h)
V_{85VBC}	85th percentile speed before the start of vertical curve (km/h)
V_{85VMC}	85th percentile speed at middle of the vertical curve (km/h)
V_{85HAT}	85th percentile speed at approach tangent of horizontal curve (km/h)
V_{85HMC}	85th percentile speed at middle of the horizontal curve (km/h)
V_{85MC}	85th percentile speed at mid-curve of point (km/h)
V_{85AT}	85th percentile speed on approach tangent speed (km/h)

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