Abstract

The purpose on this paper is to develop the 85th percentile operating speed models at mid-curve that can be integrated based on speed at the approach tangent line and radius of simple horizontal curves. This research paper presents an empirical research and presents the empirical model to predict the 85th percentile operating speed models for the horizontal curve on Malaysian two-lane rural highways conditions. The speed data measurement is based on Spot Speed Data at specified points and location using instrumentation called Laser Gun Meter Detector. Multiple linear regression equations were developed to predict the $V_{85}$ of vehicles on horizontal curves in two-lane rural highways. The geometric parameters such as radius of curve and speed at the approach tangent line are used to recognize the effect of $V_{85}$ operating speed models at the mid-curve. If this 85th percentile operating speed prediction model using multiple linear regression analysis is implemented and enhanced into current guideline and standard in Malaysia, it could play an important role in designing or redesigning of the horizontal alignment for two-lane rural highway in Malaysia.

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Keywords: Design Speed; Ergonomic Design; Horizontal Alignments; Malaysia Rural Highways; Operating Speed Model

1. Introduction

A growing concern has brought more attention to road safety to the fact that traffic collisions have become a major source of social and econometric losses in recent years. Malaysia is facing a serious road accident problem. For the last 10 years since 2000, statistics indicate that (Figure 1) about 5000 to 7000 people were killed on road (Department of Road Safety Malaysia) (DRS, 2009). According to the Malaysian Institute of Road Safety Research (MIROS, 2007) the responsibility of designing the system lies with the road designer, as seen in this statement “the designers of the system are always ultimately responsible for the design, operations and use of road transport system”. The new paradigm shift adopted by MIROS such as “shared vision” and “shared responsibility” need to be translated into action in order to support the mission. This study is an attempt to harmonize the designer adoption in designing highway and the road user expectation towards an ergonomic approach. The terminology of “ergonomic” means that the designer needs to take into consideration of road user expectation and ability or consideration of human factor in engineering design so that the traffic collision due to sub-standard and inconsistency of highway design can be reduced or eliminated.
2. Problem Statements

The present design practice in Malaysia, Technical Instruction (Road) 8/86 'A Guide on Geometric Design of Roads', (1986) and REAM Guideline 2/2002 'A Guide on Geometric Design of Roads', (2002) only set consideration the individual elements for which the geometric parameters should be selected or determined to satisfy the minimum requirement and do not consider the ergonomic element in consideration of the human factors for roadway design since approach for design speed concept only applies to horizontal curves independently and also do not take into consideration the tangents between these curves in an integrated manner.

The conventional approach of design in Malaysia does not provide any guidance in determining the maximum tangent length. Therefore, the highway designers are not able to control the maximum operating speeds on tangents since longer tangents encourage higher operating speeds and drivers may have to reduce their speeds significantly or make abrupt changes when they are approaching a sharp curve after driving a long and straight road segment. Note that highways in rural areas of the country are generally designed to give road users both accessibility and mobility.

There is no in-depth investigation being reported on the model of the 85th percentile operating speed for horizontal alignments on two lane rural highways in Malaysia. This research is actually very important in designing or redesigning the horizontal alignments especially for two lane rural highways where the highways convey high traffic speed. So far, the evaluation of the horizontal alignments design is based on the relationship of operating speeds and other elements. Therefore, this research proposes a model for evaluating the speed of 85th percentile operating speed for horizontal alignments on two lane rural highways with the development of an operating speed model is based on local empirical data.

3. Research Objective

The purpose of the study is to develop the 85th percentile operating speed model at mid-curve that can affect the highway geometry in horizontal alignments by apply simple and multiple linear regression analysis. The model can be used to estimate and predict the operating speed of passenger vehicles. The objective of this research is to develop of the $V_{85}$ speed model. Finally, the parameters that are highly correlated between driver speed behavior and highway alignment can be justified based on the design standard and can also assist the practitioners towards the best practice in highway geometric design on two lane rural highways conditions in the country.
4. Literature Review

4.1. Terminology

Definition of speed can take many forms and one of the main elements is the geometric design. The term ‘speed’ is a general term typically used to describe the actual speed of a group of vehicles over a certain section of the roadway (Fitzpatrick et al., 2003). Based on The AASHTO’s, American Association of State Highway and Transportation Officials, (2004) title on ‘Policy on the Geometric Design of Highways and Streets’, the term ‘design speed’ used to determine the various geometric design features of the roadway. The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, and the functional classification of the highway. The ‘operating speed’ is 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. Fitzpatrick et al., (1999) found that the speed at or below which 85% of drivers are operating their vehicles. But Poe et al., (1996) indicated that the speed selected by the highway users when not restricted by the other users (i.e. under free flow conditions). In term on ‘85th percentile operating speed’, the distribution of observed speeds is the most frequently used descriptive statistic for the operating speed associated with a particular location or geometric feature (AASHTO, 2004). Based on local condition Road Engineering Association Malaysia, (REAM, 2002) in term of the design speed concept, speed must be selected to establish the specific minimum geometric design elements for a particular section of the highway. Other features such as widths of pavement and shoulders, horizontal and vertical alignment and etc. are generally related to the design speed.

4.2. Previous models and predictors on predicting speeds on two-lane rural highway

A summary for the predictor variables used in the previously developed models is presented in Table 1.

| Author and Country         | Year | Model | Predictors |
|---------------------------|------|-------|------------|
| United States             |      |       |            |
| Glennon et. al            | 1986 | V₈₅   | R          |
| Lamm and Choueiri         | 1987 | V₈₅   | CCR,R,Lₙ₆₅,Sₙ₆₅ |
| Ottesen and Krammes       | 1994 | V₈₅   | CCR,R      |
| Islam and Seneviratne     | 1994 | V₈₅   | D₉₅        |
| Krammes et. al            | 1995 | V₈₅   | D₉₅,Lₙ₆₅,Dₙ₅,Lₙ₅,Vₙ₅ |
| Voigt                     | 1996 | V₈₅   | R          |
| Pasetti and Fambro        | 1999 | V₈₅   | R          |
| Fitzpatrick et. al        | 1999 | V₈₅ₕ  | R,L₉₅      |
| Fitzpatrick et. al        | 2000 | V₈₅   | R,K,G      |
| Ottesen and Krammes       | 2000 | V₈₅   | D₉₅,Cₙ₅    |
| McFadden and Elefteriadou | 2000 | 8₅₉₆.allocate | V₈₅ₙ₅,Lₙ₅ₙ₅,R |
| Jessen et. al             | 2001 | V₈₅   | Vₙ₅,G₁,ADT |
| Donnell et. al            | 2001 | V₈₅   | R,G₁,G₂,Lₙ₅ₙ₅,Lₙ₅ₙ₂ |
| United Kingdom            |      |       |            |
| Kerman et. al             | 1982 | V₈₅   | R,Vₙ₅      |
| Spain                     |      |       |            |
| Castro et. al             | 2006 | V₈₅   | R          |
| Canada                    |      |       |            |
| Morral and Talarico       | 1994 | V₈₅   | D₉₅        |
| Geometric design guide for Canadian roads | 1999 | V₈₅   | Lₙ₅,Cₙ₅,R |
| Gibreel et. al            | 2001 | V₈₅   | R,Lₙ₅,G₁,G₂,A,Lₙ₅,e,K,Dₙ₅ |
| Misaghi and Hassan        | 2005 | V₈₅₉₆.allocate | R |
Continued Table 1: Previously Developed Speed Prediction Models

| Author and Country      | Year     | Model | Predictors                  |
|-------------------------|----------|-------|-----------------------------|
| **Australia**           |          |       |                             |
| McLean                  | (1978)   | $V_{85}$ | $R, CCR$                    |
| McLean                  | (1979)   | $V_{85}$ | $R, V_{TF}$                 |
| **Germany**             |          |       |                             |
| Guidelines for the      | (1984)   | $V_{85}$ | $CCR, L_W$                  |
| design of roads         |          |       |                             |
| **France**              |          |       |                             |
| Setra                   | (1986)   | $V_{85}$ | $CCR$                       |
| Cardoso et. al          | (1998)   | $V_{85}$ | $R, V_{ASST}$               |
| **Finland**             |          |       |                             |
| Cardoso et. al          | (1998)   | $V_{85}$ | $R, V_{ASST}$               |
| **Portugal**            |          |       |                             |
| Cardoso et. al          | (1998)   | $V_{85}$ | $R, V_{ASST}$               |
| **Jordan**              |          |       |                             |
| Al-Maseid et. al        | (1995)   | $V_{85}, AV_{85}$ | $D_C, P_{con}, G, R_1, R_2, L_T, DF_1, DF_2$ |
| AbdelWahab et. al       | (1998)   | $V_{85}, AV_{85}$ | $D_C, DF$                   |
| **Greece**              |          |       |                             |
| Kanellaidis et. al      | (1990)   | $V_{85}$ | $R$                         |
| Lamm et. al             | (1995)   | $V_{85}$ | $CCR$                       |
| Cardoso et. al          | (1998)   | $V_{85}$ | $R, V_{ASST}$               |
| **Italy**               |          |       |                             |
| Crisman et. al          | (2004)   | $V_{85C}$ | $R, V_{env}$               |
| Dell’Acqua et. al       | (2007)   | $V_{85T}, V_{env}, V_{85C}$ | $V_{85CP}, V_{env}, CCR, L_W, L_T$ |
| **Pakistan**            |          |       |                             |
| Memon et. al            | (2008)   | $V_{85MC}, MaxV_{85}$ | $R, L_C, L_T, R_1, R_2, MaxV_{85T}$ |
| **Iran**                |          |       |                             |
| Azad and Behbahani      | (2010)   | $V_{85}$ | $R, L_Y, G_1, G_2$          |

Where:

- $A$: algebraic difference of vertical grades (%);
- $ADT$: average daily traffic (vehicles/day);
- $CCR$: curvature change rate (degree/km);
- $DC$: degree of curve (degrees);
- $DF$: deflection angle (degrees);
- $DF_1$: $DF_2$: deflection angle for curves 1 and 2 of compound curve (degree);
- $E$: $e$: super elevation rate (%);
- $G$: vertical grade (%);
- $G_1$: gradient preceding the curve (%);
- $G_2$: gradient succeeding the curve (%);
- $k, K$: length of vertical curve for 1% change in grade (%/m);
- $L_C$: length of curve (m);
- $L_T$: length of tangent (m);
- $L_O$: distance between horizontal and vertical point intersection (m);
- $L_{T1}$: length of preceding tangent (m);
- $L_{T2}$: length of succeeding tangent (m);
- $L_Y$: $L_C$: length of vertical curve (m);
- $L_W$, $S_W$: lane and shoulder width (m);
- $MaxV_{85T}$: maximum 85th percentile speed on approach tangent (km/h);
- $R$, $RC$: radius of curve (m);
- $R_1$: radius of preceding curve (m);
- $R_2$: radius of succeeding curve (m);
- $85_{MSR}$: maximum speed reduction from tangent to middle of curve (km/h);
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\[ V_{85} \] is the 85th percentile speed (km/h);
\[ V_{85c} \] is the 85th percentile speed on curve (km/h);
\[ V_{85mc} \] is the 85th percentile speed on middle curve (km/h);
\[ V_{85t} \] is the 85th percentile speed on tangent (km/h);
\[ V_{env} \] is the maximum speed on tangent (km/h);
\[ V_F \] is the desired speed (km/h);
\[ V_T \] is the approach tangent speed (km/h);
\[ V_A \] is the curve approach speed (km/h);
\[ V_P \] is the posted speed limit (km/h);
\[ P_{con} \] is the pavement condition;
\[ \Delta V_{85} \] is the 85th percentile speed differential calculated as different between \( V_{85} \) on two elements.

In the previous research, most of the models developments are based on spot-speed data using equipment radar or laser gun, video camera recording, speed trap recording, stop watch and the latest technology used by Memon et. al (2008) in Pakistan using Global Position System GPS – VBOX equipment at specific location. In Malaysia, there is no in-depth investigation that has been reported on the 85th percentile operating speed model for horizontal alignment that reflect on Malaysian rural highway condition. Up to this date, Technical Instruction (Road) 8/86 ‘A Guide on Geometric Design of Roads’ (1986) only set consideration on the individual elements for which the geometric parameters should be selected or determined to satisfy the minimum requirement and no design consistency models that can be used to evaluate the geometric design on horizontal alignment at two lane rural highway.

5. Methodology

For this research, the preliminary operating speed model had been developed to evaluate the 85th percentile operating speed and it can be used to predict the speed that can match the acceptable design speed. The research flow focused on the operating speed for horizontal alignments that includes the field work, data collection, and surveying works. The stages is as shown in Figure 2 where the raw data collected were process in order to obtain database for analysis and followed with model development.

5.1 Site Selection

Malaysia has different categories of highways road design. In Technical Instruction (Road) 8/86, 1986), the design standard is classified into seven groups (R6, R5, R4, R3, R2, R1 & R1a) for rural areas and into seven groups (U6, U5, U4, U3, U2, U1, & 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 road which serve local traffic, where the effect of speed is less significant can have a lower design speed. Also 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 have higher accident problem. The study area have criteria such as the classification of road is R5 Standard, which means in (REAM, 2002) 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 90 km/h. The speed data were collected for all types of vehicles in traffic stream under free flow conditions. The horizontal site were selected with the following criteria; (i) no intersection being along this site; (ii) no physical features that make an obstruction of operating speed such as speed reducer, or traffic light system along the site; (iii) the road must good dry condition because in wet or rainy condition that make the operating speed become slow.

5.2 Geometrical Data

The study areas have geometric information in construction drawing plan from the respective Public Works Department of Malaysia (PWD) officials. For the horizontal curve, the data included; degree of curvature (DC), radius of circular curve (RC), length of circular curve (LC), length of approach 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 include the K-value, gradient of the curve (G), radius of circular curve (RC), length of the
circular curve (LC), the mile point of the beginning of the curve (VPC), the point of intersection (VPI), and the end of the curve (VPT). All these geometrical data are needed for the analysis and the model development.

![Flowchart of Research Process](image)

5.3 Data Collection

Horizontal alignment is the main concern for this study. The horizontal alignment of a road consists of the straight line, circular curve and spiral curves. These types of curves are usually the segments of circles which have radius and approach tangents those provide a smooth flow of traffic along the curve. The data collections at site involve observation and take the speeds of the vehicles. The speed data were collected at every 15 minutes in one and half hour for every curve. The total number of observations is 22 hours. The total number of sample every 15 minutes is 88 samples. The speed of different type of vehicles was collected by observation value using laser gun meter detector. The data collected will be record in the data form to make it easy for further analysis. The observations of speed are recorded at three points along the curve, which is in beginning point curve, middle point curve, and end of the curve. These types of curves are usually the segments of circles which have radius and gradient those provide a smooth flow of traffic along the curve. The operating speed of the vehicle at the curve is depends on the radius and length as shown in Figure 3 sketch. It is important to know the radius of the curve to distinguish the different between the operating speeds of the vehicle at different radius. A preliminary survey was conducted along different two-lane rural roads to locate the section in different alignment of selected sites area. On other hand, the test sections along horizontal alignment consisted curves of radius >2000 m followed by long tangent, and some contained series of curve of radius <1000 m followed by short tangent. The summary of available geometric design data of the test sections is presented in Table 2.
Table 2: Detail of selected section

| Data                                | Horizontal     |
|-------------------------------------|----------------|
| No. of curve                        | 6              |
| No. of hours recorded               | 22             |
| No. of sample in 15 minute          | 88             |
| Radius of horizontal curve, RC (m)  | 800-2000       |
| Length of curve, LC (m)             | 250-600        |
| Approach tangent, LT (m)            | 350-1200       |

Figure 3: Sketch of observation point for speed measurement.

5.4 Data Reduction

The major tasks of these studies are the collection and reduction of field data to be used in developed of 85th percentile operating speed models. These data include operating speed and geometric data at the selected area. Systematic filling spreadsheet systems were applied to organize all the data. The geometric data from the data collection sheets were entered into a spreadsheet too. In order to achieve the objectives, data from six sites were used for further analysis in multiple linear regression analysis. These six sites was carried out for the operating speed observation with different horizontal curves parameter such as length of approach tangent, length of curve, and radius of curve at each curves section were carefully investigated. Observations of operating speed behavior in horizontal curves were carefully investigated. The speeds data were collected in 15-minute period. The 15-minute period was choose because speeds data from these different periodic counts make the number of sample for used in regression analysis to developed the models. The 85th percentile speed were calculated using the analysis of spot speed data process. The data collected in spot speed studies are usually taken only from sample vehicle at the selected area on which the study conducted. These data are used to determine the speed characteristics of the whole population of vehicles traveling on the selected area. So, it necessary to use statistical methods in analyzing the 85th percentile speeds (Garber and Hoel, 2002). The multiple linear regression analysis was performance by using Minitab release 14.12.0 (Minitab Inc., 2004) statistical software to develop a model that will represent the speed characteristics for the selected curves. Several models were performed and only the significant and logical models were presented. The following conditions were adopted in the regression analysis to develop the final models. There were; i) each of the independent variables used in the model must have a regression coefficient that is significantly at the 95% coefficient level. ii) the algebraic signs of the coefficients of the independent variables must have a logical explanation with reality of traffic theory and philosophy.

6. Development of 85th Percentile Operating Speed Model

6.1. Descriptive analysis for the 85th percentile operating speed on horizontal curve

To develop the 85th percentile operating speed models at mid-curve, the operating speed at mid-curve and speed at approach tangent has been collected and recorded and then 85th percentile operating speed was calculated. Then, the regression analysis was carried out using Minitab release 14.12.0 (Minitab Inc., 2004). Data screening needs to be conducted before using the reduced data for analysis to correctly identify data errors (Norusis, 1994). The data screen includes removing the unusual observation. The unusual observation indicates that, some data collection are missing because of the carelessness of enumerator to take the speed value at site location and taking speed of police car, ambulance or fire brigade truck. The speed is higher than the normal operating speed because they travel for emergency situations. So the total numbers of samples after removing the unusual observation are 78 samples. Histogram was generated as shown in Figure 4. The number of observation, mean, median, maximum value, minimum value, standard deviation, skewness and kurtosis for parameter $V_{85}$ are as shown in Table 2. In general all the graphs were distributed in mound-shape curve and this follow the empirical with 95% confident level. The mean and median are the most commonly reported measures of central tendency. The median represents the middle value.
in a series of measurements that have been ranked in incremental order. In the case of an even sample size the median is the average of the two middle values. Average or arithmetic mean is computed by dividing the sum of individual observations by the total number of observations. In the case of symmetrical distribution, mean and median are expected to be the same value. For a skewed distribution, the mean is larger than the median if the tail extends toward larger values and smaller than median if the tail extends toward smaller values.

6.2. Interpretation of the Multiple Regression Statistics for V85 model

The multiple regression equation for V85MC model is shown in equation 1. Table 3 shows that the inverse square root of length radius of curve (1/\(RC\)) and 85th percentile speed at approach tangent line (V85AT) are very significant independent variables for predicting V85 where the p-value is less than 0.05. This means that the predictor is significant for both independent parameters and that these parameters can be included in the model for estimating V85MC.

\[
V_{85MC} = 75.344 - \frac{368.14}{\sqrt{RC}} + 0.307V_{85AT} \quad (R^2 = 0.532)
\]

The equation above shows that the coefficient for the predictor variable 1/\(RC\) has a negative sign, implying that an increase in the radius of curve, will lead to a decrease in the V85MC operating speed at mid-curve and variable V85AT has a positive sign implying that an increase operating speed at approach tangent line, will lead to an increase in the V85MC operating speed at mid-curve. The standard error contains the same units as the coefficients. The relative value of standard error to the coefficient is important in determining the reliability of the test statistics in estimating the population parameter (Faria, 2003). In general, the smaller the value of the standard error in relation to the test coefficient the better is the result.
6.3. Analysis of variance test for $V_{85MC}$ model

Analysis of variance consists of calculations that provides information about levels of variability within a regression model and forms a basis for tests of significant. The analysis of variance portion of the output is shown in Table 4. The degrees of freedom are provided in the “DF” column, the calculated sum of squares terms are provided in the “SS” column, and the mean square terms are provided in the “MS” column. The P-value for the F test statistics = 42.63 for horizontal curve which is less than 0.001, provides strong evidence against the null hypothesis or $H_0$ is rejected and the independent parameters provides valuable information for predicting $V_{85}$.

Table 4: Analysis of Variance for Final Model $V_{85MC}$

| Regression $V_{85MC}$ | DF | SS   | MS   | F     | P      |
|-----------------------|----|------|------|-------|--------|
|                       | 2  | 1346.77 | 673.39 | 42.63 | 0.000  |
| Residual error $V_{85MC}$ | 75 | 1184.83 | 15.80 | -     | -      |

6.4. Scatter Plot of Residuals for $V_{85MC}$ model

After the fitting regression plane for $V_{85MC}$ model is checked, it is important to investigate the residuals to determine whether or not they appear to fit the assumption of a normal distribution (Mendenhall et al. 2006). The residuals do not seem to deviate from a random sample from a normal distribution in any systematic manner as shown in Figure 5. The principle of regression assumes that the errors between the predicted and measured values should be normally distributed and for this reasons. Kolmogorov-Smirnov Test Normality and Durbin-Watson Statistic Test Normality was conducted and the result is as shown in Table 5. In Figure 6 the normal probability plot shows that the residuals were scattered closely to the line, therefore the model justifies the regression assumption.

![Figure 5: Residual versus the fitted values for final model $V_{85MC}$ model](image1)

![Figure 6: Normal probability plot of $V_{85MC}$ model on Kolmogorov-Smirnov Test Normality](image2)

The hypothesis test for Kolmogorov-Smirnov Test Normality can be stated as follows:

(i) $H_0$: The residual for $V_{85MC}$ model is normal.
(ii)$H_1$: The residual for $V_{85}$ model is not normal. If the P-Value is greater than $\alpha = 0.05$ or equal to 0.05, $H_0$ is not rejected. The residuals are normal for final model $V_{85MC}$ and hence there is no reason to doubt the validity of the regression assumptions. The Durbin–Watson statistic is a test statistic used to detect the presence of autocorrelation in the residuals from a regression analysis. The value of Durbin-Watson statistic, $d$ always lies between 0 and 4. If the Durbin–Watson statistic is substantially less than 2, there is evidence of positive serial correlation.

Table 5: Test of Normality

| Test of Normality       | Value |
|-------------------------|-------|
| Kolmogorov-Smirnov Test | 0.089 |
| Durbin-Watson statistic, $d$ | 1.49103 |
7. Discussion and Conclusion

The 85th percentile operating speed models at mid-curve linear regression models for the Malaysian rural highway traffic have been successfully developed in this study. Based on the equation or model develop, the variable radius of curve (RC) can be rearranged to get a specific the radius of horizontal curve. The specific radius value is to ensure the appropriateness for purpose in design. This model consists important various aspects of operating speed on approach tangent line and geometric designs of horizontal alignment of rural highways. The models developed must be evaluated to check its ability to represent actual condition and to explain the variability present in a sample other than the used for its calibration. Therefore, the design speed concept needs to be understood well especially in the rural highways. The outcomes from this study are valuable and can be used to implement and enhancement into current guideline and standard in Malaysia, it could play an important role in designing or redesigning of the horizontal alignment for two-lane rural highway in Malaysia.

8. Acknowledgement

The authors would like to thank Kamal, M.N., Ismail, N.S., Abd Makatar, M.A., and Musa, M.L. from Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM) for their significant contribution for this study. Appreciation also goes to the Research Management Institute (RMI, UiTM) for providing grant research grant (Fundamental Research Grant Scheme, FRGS). Thank you is also extended to all individuals and organization that have made this study possible.

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