Speed Hump Model: A Case Study in Malaysia Residential Streets

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Abstract: -Speeding and speed control are often considered critical issues on residential and collector streets. In addition, speeding complaints are a continuing problem for traffic engineers and police department. Supporting the idea of controlling speeds is the assumption that reducing speeds also reduces accidents. However, different speed limits require different speed hump profile. In Malaysia, speed hump design varies widely between road authorities, some of the dimensions designed by the local authorities been implemented on an 'ad hoc' basis without any proper standards or guidelines [1]. With many styles and inconsistencies, a study to develop an optimal speed hump geometric design was needed considering the observed 85th percentile speed and speed hump geometric design at 76 implemented speed hump location. After several analyses were conducted one model with R-Sq value of 80.6% was developed using multiple linear regressions. The model was further validated using about one third of a new data set from the overall data used in the model development. It was found that the model was reliable which produce small discrepancies when compared between the empirical and predicted results. Hence, the models can be accepted and considered reasonable for the purpose of this study.

Key-Words: 85th percentile speed, traffic calming, speed hump model.

1 Introduction

Worldwide, almost 1.2 million traffic-related fatalities and 50 million traffic related injuries occur each year, more than half of which involve pedestrians, especially in developing countries. Pedestrians were involved in about 52% of traffic fatalities in New York between 2005 and 2009 [2]. Moreover, it is anticipated that these traffic fatalities and injuries will increase by 65% by 2020 owing to the rapid increase in individual vehicle use in developing countries [3].

Malaysia has experienced rapid developments in the field of road transport for the past twenty years. This rapidity originates from the high population growth rate, urbanization process and the country's economic development. Together with this rapidity, the total number of vehicles registered has increased each year. This has resulted in an increase of the traffic volume as well as the accident rate both for drivers and pedestrians. According to the Malaysian Institute of Road Safety Research 6,872 to 7,152 people have perished annually on Malaysian roads and highways each year between 2010 and 2016; a relatively high figure considering the country's population of only 31 million [4].

Therefore, governments and transportation agencies need to adopt policies to reduce the threat posed to pedestrians by high-speed vehicles in residential areas [5]. Such policies include traffic calming. According to Lockwood [6], "Traffic calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior, and improve conditions for non-motorized street users."

Between all of the traffic calming measures that have been developed, speed hump is the best in terms of reducing the speed of vehicles [7-10]. Speed humps are raised sections of roadway designed to limit the speed of motor vehicles. They are four meters long, between 76 to 100 millimetres high, and can cover all or a portion of the width of a roadway. A speed hump is not the same as the much shorter speed bump as shown in Fig. 1.

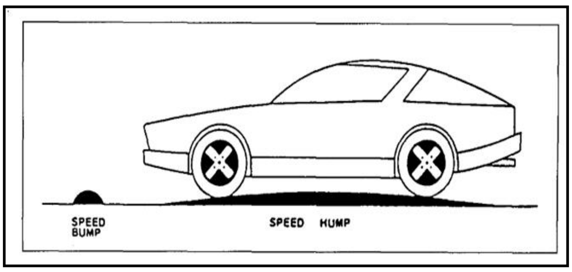

Figure 1. Profile of Speed Hump vs. Speed Bump [11]

2 Problem Statement

Although speed humps have been positively received by local residents in Malaysia. Some of the dimensions are designed by local authorities; however most of them had been implemented on an 'ad hoc' basis without proper standard or guidelines, but purely on the basis of experiences of the local traffic engineer and requested from the residents [1].

As to date few guidelines have been introduced in Malaysia stipulating specific range of dimension. Unfortunately, no perfect and ideal guidelines were introduced and were never properly enforced by the local authorities. Therefore, with many styles and inconsistent design, the function of speed hump in reducing speed may not be accomplished. A high speed leads to a greater risk of a crash and a greater probability of serious injuries. Besides that, at high speed, errors by the driver are magnified [12]. A high speed in an inappropriate situation such as a residential area does not only increase the risk of accidents but also generally declines the residents' concern on the safety and comfort levels for pedestrians as well as for motor users into residential streets [13].

In this study, a statistical relationship between geometric characteristics of speed control humps and 85th percentile speeds of the automobiles are developed and model have been suggested for the use of practicing engineers. This relationship can be used as a tool for designing hump geometry for a particular hump-crossing speed. One of the important features of the study is the development of a simple procedure for the road hump design.

3 Methodology

For this research, the 85th percentile speed reduction model has been developed in relation to speed hump geometric design. The research flow for this research started with site selection criteria, speed hump geometric data collection, spot speed data collection, and statistical analysis.

3.1 Site Selection Criteria

Site Selection Criteria is set as a guide to select a suitable speed hump location in residential area. The site selection shortlisted only the sinusoidal types of speed humps that have different geometric design since this type of hump is commonly used in the case study area. The selected site is chosen accordance to these following conditions:

a) The speed hump locations are rejected if they are as follows:
   i. Near signalized (push-button) pedestrian crossing facilities;
   ii. Nearby signalized or non-signalized intersection;
   iii. At a dead-end road;
   iv. Near infrastructure that will eventually reduce the traffic speed within the residential area; or
   v. At a curve or downhill area.

b) The speed hump locations are selected if they have the following:
   i. Existing speed hump at the collector or local streets in residential area with a design speed of no more than 50km/hr according tothe Public Works Department's guidelines [14].
   ii. Sufficient vehicle volume to allow adequate
   iii. data collection for speed so that a minimum of 50 sample size can be obtained within an hour; and
   iv. Minimal flow interruption at the speed hump location which means there is no presence of traffic warden and parked vehicles that could disrupt the free traffic flow.

3.2 Speed Hump geometric data collection

Geometric information was collected at the selected speed hump location. This include height, length, and width of the speed hump without considering the aspect of the layout design such as spacing, materials, marking, and signage. Theodolite (survey equipment) was used to measure the height of the speed humps; small measuring wheels were used to measure the length and width. The geometric information in Fig. 2 obtained from the Standards and Industrial Research Institute of Malaysia [15].

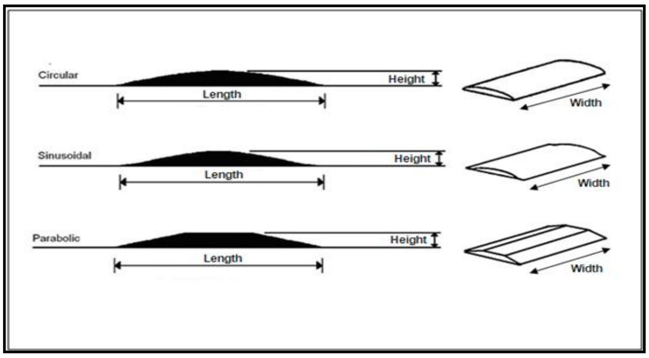

Figure 2. Common Shapes and Dimensions of Speed Humps [15]

3.3 Speed Data Collection

The acquisition of speed data was carried out by means of a leaser speed gun over the existing speed hump location. For every site, a minimum of 50 spot speed measurements were collected during the off-peak hour at 3 different points within the speed hump location. The speed of only the passenger cars was collected at a minimum of one hour at every site. The data collected are recorded in the spot speed data form to facilitate further analysis. The speed at every site were obtained and compiled with the other speed hump locations.
As such the 3 types of speed reading taken at respective point are shown in Fig. 3:

Point A – the speed at the point where the vehicle is 15 meters before the speed hump

Point B – the speed at the point where the vehicle is on the speed hump

Point C – the speed at the point where the vehicle is 15 meters after the speed hump

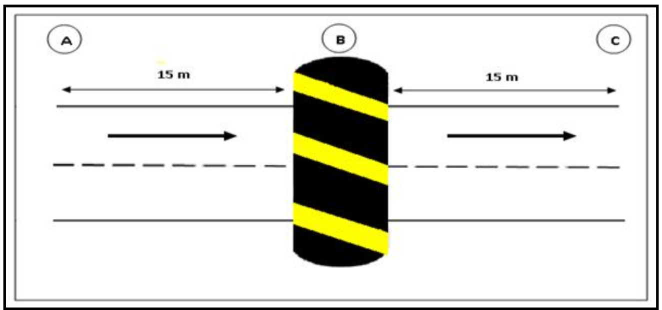

Figure 3. Spot Speed Study

This study considers the spot speed study approach because it is related to the vehicle's 85th percentile speed distribution in determining the existing traffic operation and control. The 85th percentile operating speed was calculated using the interpolation method. The 85th percentile speed for each location was gathered and used to evaluate and identify the adequacy of the speed hump geometric elements such as height, length and width of the speed hump in relations to the 85th percentile speed. The 15 meter distance before and after the speed hump was selected due to the previous studies that considered the 85th percentile speed at ranges between 5 meter to 30 meter before and after the speed hump [16-18]. In this study, 15 meter was chosen for the 85th percentile speed data collection before and after the speed hump as 15 meter lies in the range of distance applied in other studies. Moreover, from the case study location it is observed that a distance that is more than 15 meter at most of the hump location areas resulted in an interruption of traffic flow especially due to the intersections.

4 Analysis of Data and Result

After collecting the data at the fieldwork, the data should be screened by resolving any ambiguities, errors, and removing redundant and problematic data. The error may exist due to several factors such as during data collection process, transferring data onto sheets, equipment malfunction and error during construction of cumulative frequency curve graph to get the 85th percentile speed. By using statistical software called Minitab 16.0, these errors or so call outliers can be removed by using box plot. Failure in this step will cause distortion in future models development. Once screening process is completed, model development phase is employed by adopting multiple linear regression analysis. Multiple linear regression analysis is an extension of simple linear regression to allow for more than one independent variable [19]. This type of analysis applies when several predictor variables exist. By considering several predictor variables, x, x_1, x_2, x_3,.........x_n the analysis can provide better explanation of the dependent variables, Y and the model is useful in prediction modelling.

The descriptive statistics after the identification and removal of outliers are shown in Table 1. The total number of samples after removing the outliers is 68 samples. Referring to Table 1 the values of the skewness and kurtosis for most of the variables accept length (L) and width (W) were near to zero. According to [20], a normally distributed sample has a skewness and kurtosis value of zero. This shows that the data in general are normally distributed following the empirical rule with 95% confident level [19].

Table 1. Summary of Descriptive Statistic

Variable	No. of observation	Mean	S.E Mean	StDev	Min.	Median	Max.	Skewness	Kurtosis
Vab (km/hr)	68	14.678	0.482	3.973	5.5	14.423	22.031	-0.04	-0.44
Vbc (km/hr)	68	-7.541	0.381	3.145	-14.219	-7	-1	-0.23	-0.53
Vac (km/hr)	68	7.137	0.31	2.554	0.195	7	14.063	0.08	0.23
Va (km/hr)	68	31.133	0.479	3.953	22	31	38.521	0.08	-1.04
Vb (km/hr)	68	16.455	0.381	3.143	11	16	27.867	0.97	1.67
Vc (km/hr)	68	23.996	0.382	3.15	16.867	24	30.7	-0.05	-0.42
H (m)	68	0.07316	0.00206	0.01695	0.05	0.07	0.12	0.9	0.62
L (m)	68	1.9456	0.0629	0.5185	1.2	1.9	3.5	1.47	2.36
W (m)	68	7.724	0.205	1.693	1.1	7.4	11.2	-1.14	5.9

Analysis on variables correlation helps to measure the degree of linear relationship between two variables. For the purpose of analyzing the correlation among variables, hypotheses are set as show in Fig. 4.

H_0 = There is no correlation between two variables.
H_1 = There is a correlation between two variables.

Figure 4. Hypothesis for correlation analysis

From the output of correlation analysis shown in Table 2, it was found that among the speed hump geometric designs, H (r=0.387, p-value<0.05) was positively correlated to V_{ab} compared to V_{bc}, V_{ac}, V_a, V_b and V_c . Other speed hump geometric designs variables such as L and W had a low r value and a p-value of > 0.05 indicating that the variable was not significant for the individual hypothesis test and thus H_0 was not rejected instead H_0 was accepted, for variable L and W. The results of the correlation analysis showed that the Height of the speed hump (H) was significantly correlated with the 85th percentile speed reduction from point A to point B (V_{ab}). This is logical because the height of the speed hump may determine the driver's perception in reducing the speed when travelling on the speed hump comfortably. To a certain extent, V_{ab} was significantly related to H and should be selected in the model development.

Table 2. The Correlation Matrix among Variables

	Vab	Vbc	Vac	Va	Vb	Vc	H	L
Vbc	-0.766	_	_	_	_	_	_	_
	0							
Vac	0.612	0.039	_	_	_	_	_	_
	0	0.75						
Va	0.685	-0.374	0.606	_	_	_	_	_
	0	0.002	0					
Vb	-0.402	0.498	-0.011	0.391	_	_	_	_
	0.001	0	0.927	0.001				
Vc	0.364	-0.501	-0.051	0.764	0.501	_	_	_
	0.002	0	0.682	0	0			
H	0.387	-0.354	0.167	0.126	-0.331	0.022	_	_
	0.001	0.003	0.174	0.308	0.006	0.856		
L	0.147	-0.125	0.075	0.062	-0.107	0.017	0.241	_
	0.231	0.311	0.542	0.613	0.383	0.888	0.048	
W	0.162	-0.007	0.243	0.233	0.089	0.096	-0.148	0.082
	0.187	0.953	0.046	0.055	0.471	0.436	0.228	0.506

The V_{ab} model includes variables such as 85th percentile speed at point a (V_a), 85th percentile speed at point b (V_b), Height (H) and Length (L) of the speed hump geometric as the predictor. In this study, the predictor variables were transformed using normalization to follow a normal distribution. Table 3 shows the constant value, the transformed predictor of V_aHL and V_bHL.

From Table 3, it is noted that V_aHL and V_bHL were significant independent variables for predicting V_{ab} where the p-value was less than 0.05, meaning that the null hypothesis (H_0) was rejected and the alternative hypothesis (H_1) was accepted as the hypothesis used for the F-test shown in Fig.5. Hence, these predictors can be included in the model for predicting V_{ab}.

Table 3. Regression Analysis for Final Model Estimating V_{ab}

Predictor	Coefficient	Standard Error Coefficient	T-value	P-value	VIF
Constant	12.9485	0.6197	20.9	0.00	
VaHL	4.5266	0.28	16.17	0.00	5.727
VbHL	-8.0274	0.5958	-13.47	0.00	5.727
S = 1.77717		R-Sq = 80.6%		R-Sq(adj) = 80.0%	

H_0 = The predictor cannot be used for predicting in the V_{ab} model.
H_1 = The predictor can be used for predicting in the V_{ab} model.

Figure 5. Hypothesis for F-test

The analysis of variance (ANOVA) portion of the output shows p-value is less than 0.05 in Table 4, thus rejecting the H_0 and accepting the H_1. The hypothesis for the ANOVA test is as shown in Fig. 6. Hence, the regression model was significant and thus could be used to explain or predict the V_{ab}.

Table 4. Analysis of Variance for Final Model

Source	DF	SS	MS	F-test	P-value
Regression	2	852.04	426.02	134.89	0.00
Residual Error	65	205.29	3.16	-	-
Total	67	1057.33	-	-	-

H_0 =The V_{ab} model cannot be used for predicting
H_1 =The V_{ab} model can be used for predicting

Figure 6. Hypothesis for ANOVA test

In conclusion, the equations on predicting the 85th percentile speed reduction at point a to point b (V_{ab}) were developed as shown in (1).

$$V_{ab} = 12.9 + 4.53V_aHL - 8.03V_bHL \tag{1}$$

Where:

V_{ab} = 85th percentile speed reduction at point a to point b (km/h).

V_aHL = Transformation of 85th percentile speed at point a (V_a), height (H) and length (L) of speed hump.

V_bHL = Transformation of 85th percentile speed at point b (V_b), height (H) and length (L) of speed hump.

Next, Vab is tested to confirm the assumptions used by observing the distribution of residuals of the models. The residual plots are the difference between the observed response value and the fitted response value. Figure 7 shows the residuals versus fitted values plot for Vab. From the figure, the points in the residual plots are scattered randomly at about zero. Therefore, no evidence of non-constant variance, missing terms, or outliers exists [21].

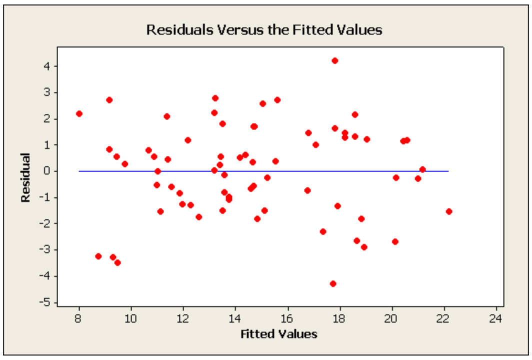

Figure 7. Residual versus Fitted Values for V_{ab} Model

The use of probability plot and goodness-of-fit tests, such as the Anderson-Darling and Kolmogorov Smirnov normality test, was to assess whether the residuals were normally distributed. As can be seen in Fig. 8 the points were scattered closely around the straight line which meant that the residuals were normally distributed [21].

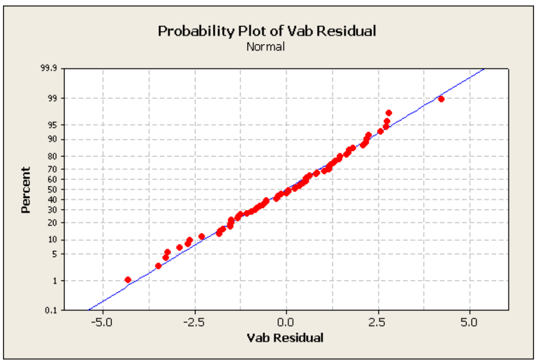

Figure 8. Normal probability plot

By referring to Table 5, since all the p-values of the Anderson-Darling and Kolmogorov Smirnov normality tests were more than 0.05, H_0 was not rejected and the null hypothesis (H_0) was accepted, and hence the residuals for the V_{ab} model followed a normal distribution curve. The hypothesis test for the Anderson-Darling and Kolmogorov Smirnov normality test is shown in Fig. 9.

Table 5. Statistical Normality Results

Statistical Test	p-value
	V_{ab}
Anderson Darling	0.854
Kolmogorov Smirnov	>0.150

H_0 = The residuals for the predicted model is normally distributed
H_1 = The residuals for the predicted model is not normally distributed are not normal

Figure 9. Hypothesis for normality test

V_{ab} is further validated using about one third of a new data set from the overall data used in the model development. This is important to ensure that V_{ab} is reliable in predicting the value of response variables. Validation was conducted by using scatter plot, equations of Root Mean Squared Error (RMSE), Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE). Lastly the paired T-test was conducted for the validation purposes.

Figure 10 represents the relationship between the empirical V_{ab} and predicted V_{ab} from the model developed in this study. The scattered points were discovered to be close to the line which generally means the predicted values matched the actual values (empirical), the model is acceptable [22].

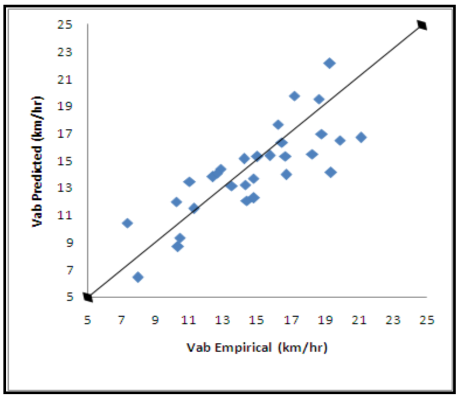

Figure 10. Predicted (V_{ab}) versus Empirical (V_{ab}) from Independent Dataset

Where:

V_{ab} Empirical (independent data set) is denoted as V_{ab} empirical (km/h)

V_{ab} Predicted using Equation 1 is denoted as V_{ab} predicted (km/h)

It was indicated in Table 6 that the RMSE deviation from the empirical value of V_{ab} was 2.18km/h. The MAE deviation from the empirical value of V_{ab} was 0.41km/h. The MAPE for V_{ab} from the empirical value was 1.38%. Thus, it can be concluded that the V_{ab} model can be acceptable to predict the 85th percentile speed reduction at point a to point b due to a small discrepancy value of the RMSE, MAE and MAPE.

Table 6. Validation Analysis Results for V_{ab} Model

Model	RMSE(km/h)	MAE (km/h)	MAPE (%)
V_{ab}	2.18	0.41	1.38

Lastly, V_{ab} is then validated by using paired t-test. Paired t-test for V_{ab} revealed that p-value is more than 0.05 shown in table 7. Therefore, the null hypothesis (H_0) was not rejected at the 5% level of significance. This indicated that the V_{ab} predicted model did not differ much from the V_{ab} empirical values. Hypothesis used for this test is as shown in Fig. 11.

Table 7. Validation by paired t-test

H_0 = The mean difference of V_{ab} empirical and V_{ab} predicted equals to zero.
H_1 = The mean difference of V_{ab} empirical and V_{ab} predicted is not equals to zero.

Test	t-statistic	p-value
V_{ab} emp vs V_{ab} predict	1.04	0.306

Figure 11. Hypothesis for Paired T-Test

5 Discussion and Conclusion

The 85th percentile speed reduction in residential streets using multiple linear regressions has successfully been developed in this study. Based on the field experiment on 85th percentile speed reduction and hump geometric design, this investigation has shown that statistically significant regression relationships could be established. The application of the developed model can be used at collectors and local streets within the residential area. Most of this street has a traveling speed of 50km/h and less[23]. Using Equation 1, the variables can be re-arranged according to what is the desired predicted variable. For example, if a car is travelling at a speed of 40 km/h (V_a) and desired 85th percentile hump-crossing speed at the street is 15 km/h (V_b), 85th percentile speed hump reduction from point a to point b (V_{ab}) can be calculate from V_a-V_b which is 25 km/h. Assume a hump height (H) equals to 0.08 meter and compute the length (L) that satisfies the developed model. Check whether the hump length (L) is acceptable. If not, repeat the step on assuming the hump height (H). Latest guidelines in Malaysia [11] have indicated that hump heights between 0.075 m to 0.1 m may be used, and that hump lengths vary from 2.5 m to 4.25 m are common. The outcome of this study is important and hopefully can be used to implement and be enhanced into current guideline and standards in Malaysia, as it could play an important role in designing or redesigning the speed hump geometric for residential area in Malaysia.

5 Acknowledgment

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