Exploration of Merging Traffic Flow at Malaysian Urban Expressway

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Abstract: The understanding of merging operational quality for expressway is very important to transportation engineers in planning, designing and maintaining the highways. Projected traffic demands along with the estimated facilities requirement to support the traffic are crucial inputs to the planning of infrastructure expansions. In the design context, the understanding of capacity analysis can assist highway designers in justifying the feasible alternative to be implemented. Traffic engineers normally utilize traffic models prediction to anticipate congestion and potential breakdown at critical areas. Through this approach, they are able to develop appropriate countermeasures and route diversion strategies as well as in developing traffic management strategies to solve the congestion on the expressway. Merging flow rates models were successfully developed and validated in these studies. They are needed in order to understand the merging operation at ramp junctions. The models are useful for estimating flow rates in lanes 1 and 2 immediately upstream of the merge influence area.

Key Words: *entrance ramp junction, merging flow rates, traffic models*

1. INTRODUCTION

Expressway represents an important part of modern highway system in both urban and rural areas in Malaysia. Expressway provides limited access because its main function is to provide free movement of traffic at high speeds. However, in recent years, motorist on this facility in Malaysia have experienced increase operational problems particularly in urban areas such as in Kuala Lumpur and Selangor. Congestion is a normal occurrence on urban Malaysian expressway system and these phenomena has to be borne by the road users. This congestion is usually associated with areas that have entrance ramp, exit ramp and weaving section.

The predictions of capacity and operational quality for expressway are very important to transportation engineers. They are for planning, designing and maintaining the highways. Projected traffic demands along with the estimated ability of facilities in carrying traffic are crucial inputs to the planning of infrastructure expansions. In the design context, the understanding of capacity analysis can assist highway designers in justifying the feasible alternative to be implemented. Traffic engineers normally utilize capacity prediction to anticipate congestion and potential breakdown at critical areas. Through this approach, they are able to develop appropriate countermeasures and route diversion strategies as well as in developing traffic management strategies to solve the congestion on the expressway.

2. PROBLEM STATEMENT

An entrance ramp-expressway junction is generally designed to permit high speed merging movements that take place with a minimum disruption to the main stream flow and provide a maximum safety to the drivers. The high speed merging is achieved due to a small difference in design speed for a ramp and the design speed of the expressway mainstream. Normally, the difference is about 30 to 50 km/hr (Hunter *et al.* 2001). Nevertheless the entrance ramp junction often leads to breakdown in operation thus reducing mobility drastically. Hence, entrance ramp junctions have been the subjects of interest to many traffic flow researchers like Roess (1980), Eleftriadou (1994), Jinchuan *et al.* (2000), Carlsson and Cedersund (2000), Lorenz and Elefteriadou (2000), Al-Kaisy (1999), Hidas (2005), Bloomberg (2006) and Dowling and Halkias (2006). Traffic engineers need to evaluate operational quality and design features of ramp-expressway junctions. A precise analysis or design of the junction is a very important task because undesirable incident at any one junction can offset the operation for the entire expressway corridor. Assessment of operational quality in such junctions is most often needed. To date there is no firm guideline, based on local empirical studies and research for Malaysian expressway condition. It is therefore necessary to establish an empirical study that evaluates the impact of the length of the acceleration lane on the operation of ramp junctions. The study also compensates for the gap of knowledge towards a more realistic merging model that reflects Malaysian expressway condition.

3. EXPRESSWAY SYSTEM: AN OVERVIEW

Expressway represents an important and integral component of Malaysian highway network. This facility is intended to provide mobility and uninterrupted traffic flow for both urban and rural areas. In Malaysia, expressway began to be constructed in 1980’s to accommodate the growth in vehicle ownership that accompanied the growth of the Malaysian economy. Therefore, there was a need to provide highway facilities that could handle large traffic volumes at relatively high speeds through full control of access and with minimal vehicular conflicts and interactions.

As defined in AASHTO (2004), expressways or freeways are highways with full control of access. They are intended to provide movement of large volume of traffic at high speeds with high level of safety and efficiency. Urban expressways usually carry higher traffic volumes with four to sixteen through-traffic lanes in both directions (Al-Kaisy, 1999). However, their design is sometimes constrained due to limited space in urban areas. In addition, design of alignment and cross section elements of rural expressway are more generous due to availability of the right-of-way at lower cost and usually associated with higher design speeds.

3.1 Expressway System Components

A freeway is defined as a divided highway facility with full control of access and two or more lanes for exclusive use of traffic in each direction (TRB, 2000). In general, almost all expressway system is made up of the following types of components sections: basic segment, merge, diverge and weaving sections, as shown in Figure 1.

Basic expressway sections consist of expressway segments that are located outside the influence area of merge, diverge or weaving sections. Therefore they are not affected by turbulence due to intensive merge, diverge or weaving activities. In order to provide access to and exit from expressway system, entrance ramp are provided to the expressway facilities. These sections are characterized by merging and diverging traffic movements and are usually associated with a considerable amount of disturbance to the traffic stream on the mainline expressway. When a merge facility involves an entrance ramp or diverges involves exit ramp, the section is referred as ramp-expressway junction. This type of merge and diverge sections is the most common on expressway systems and is normally associated with higher impacts on the expressway mainline traffic. Another section in expressway facilities is a weaving section. When a merge section is closely followed by a diverge section and connected with auxiliary lane, a crossing movements of merging and diverging vehicle take place, thus creating "weave motion" of traffic.

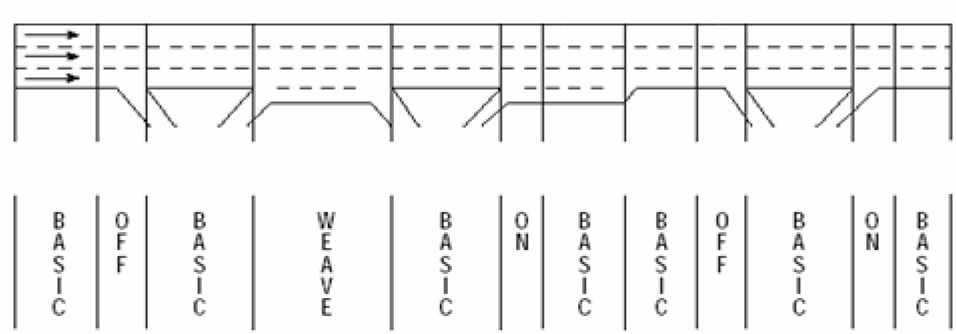

Figure 1: Freeway facility segments (TRB, 2000)

4. LITERATURE REVIEW

The current edition spell out, HCM (2000) is the first HCM to provide a technique for estimating the capacity and determining the LOS of transportation facilities including intersections and roadways. It also includes transit, bicycles and pedestrians (TRB, 2000). Each LOS is associated with a range of operating conditions and is assumed to represent traveler perceptions of various conditions.

Entrance ramp expressway junctions are generally designed to permit high speed merging movements to take place with a minimum disruption to the adjacent expressway traffic stream. Areas around entrance ramps experience more turbulence and conflicts compared to basic expressway segments (TRB, 2000). Therefore, acceleration lanes are designed to allow vehicles to merge smoothly and without causing interference to expressway traffic streams. A well-designed acceleration lane should permit ramp drivers to perform a safe merge within the effective acceleration lane length. As such, the proper design and placement of ramps on high demand expressway is crucial for fast, efficient and safe operation. Determination of expressway capacity at ramp-expressway merge junction is important for several practical reasons. The development of appropriate design for expressway merge facilities depends largely on expressway capacity and ramp capacity (Al-Kaisy, 1999). Most expressway management and ramp control strategies are developed based on the estimated capacity values of expressway components and ramp junctions. The quality of service and operational breakdown are directly associated with expressway capacity and represents the important part of any operational analysis.

5. CHARACTERISTICS OF TRAFFIC OPERATION IN MERGE INFLUENCE AREA

Merging occurs when two separate traffic streams join to form a single stream as illustrated in Figure 2. The ramp vehicle merging process is a complex pattern of driver behavior. A driver performs several different tasks during the merging process such as lane changes of ramp vehicles into the expressway mainstreams, lane changes of mainline traffic to other lane to reduce the merging ramp impact and turbulence, acceleration and deceleration behaviors due to intensive conflicts and turbulence such as searching for available gaps to make any movements (Gettman, 1998)

Various mathematical models have been developed to describe the relationships between flow, speed and density on expressway for any given instance. The models are like those of Fazio and Rouphail (1986), Shin(1993), Theophilopoulus (1986), Choocharukul (2003) and TRB (2000). The most relevant one relating to the estimation and prediction of traffic operating condition is the U.S HCM. The methodology applied in this research is the principal methodology applied in the U.S HCM 2000.

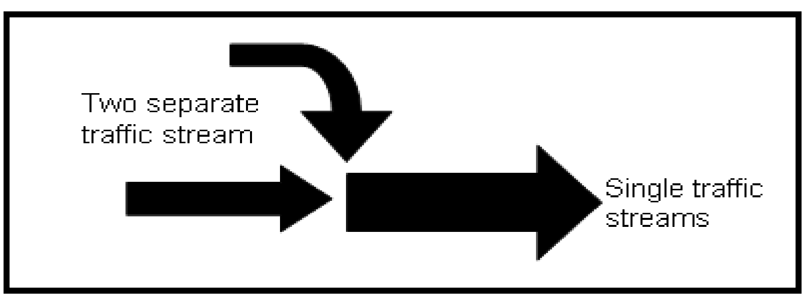

Figure 2: Illustration of merging traffic phenomenon

Theoretically, capacity of the entrance ramp is mainly a function of the ability of the merge section to accommodate mainline traffic and ramp demand. The ability to accommodate mainline traffic is primarily governed by mainline geometric characteristics such as number of lanes, lane width and lateral clearance. Apart from that, the ability of merge section to accommodate entrance ramp traffic is also influenced by the availability of gaps on the adjacent expressway lane and gap acceptance process. However, this research is concerned with analysis of operational performance at ramp expressway merge sections which deals with macroscopic traffic parameters such as flow rate, density and speed.

6. OVERVIEW OF THE PRINCIPAL METHODOLOGY

The major tasks of this research are the collection and reduction of field data to be used in calibrating entrance ramp merging models. These data include traffic density and flow rate. Obtaining accurate data is the priority of this research. Quality control is implemented throughout the data collections and reductions process. A systematic labeling procedure was used in numbering the DVD videotape recording and a comprehensive filing system were applied throughout the process. The primary data reduced were traffic flow rates and traffic density for acceleration lane and 3 lanes of expressway mainstreams. In order to achieve the objectives of this study, many operational aspects of the junctions pertaining to different lengths of acceleration lanes were carefully investigated. Macroscopic observations of merging behavior in the acceleration lanes and mainstream were particularly needed for data collection. A 5-minute analysis period was chosen because of its steadiness and stability in terms of variation in count. Normally, the longer analysis period, such as a 15-minute period, has often turned out to be inadequate to be used because within that time period, several dissimilar operations have been frequently observed (Shin, 1993; Cassidy, 1990 and Roess *et al.* 2004). The 15-minute periods often contain dramatic changes in speeds and relatively big fluctuations in counts. They need to be stratified into the shorter periods so that traffic flow can clearly be differentiated under various regimes. It is also because averages over the 15-minute periods usually distort or dilute the transition flow process (Roess *et al.* 2004). In this study it examined the effects of the length of the acceleration lanes in detail and focuses on the operation of single lane acceleration ramp merge with three lane mainstream of expressway in one direction. A total of 6 ramps -expressway junctions in Federal Highway Shah Alam-Kuala Lumpur with the different length of acceleration lanes ranging from 100m to 250 m were observed. Each site was videotaped for a period of between 8-10 hours under stable flow condition. As can be seen in Figure 3, in general the flow rates are much higher in lane 2 expressway, V_2 when compared to lane 1 expressway flow rate, V_1 at entrance ramp junction.

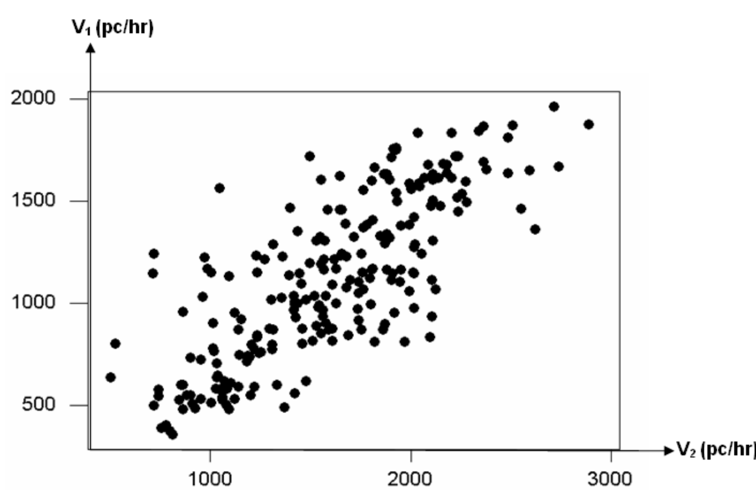

Figure 3: Measured Lane 1 Flow rates versus Lane 2 Flow rates

The action of each merging vehicle entering the Lane 1 traffic stream creates turbulence in the vicinity of the entrance ramp. Approaching expressway vehicles move towards the right to avoid this turbulence for all the sites under investigation. Past studies have shown also that the operational effect of merging vehicles is heaviest in Lanes 1 and 2 and the acceleration lane for a distance extending from the physical merge point to 450 m downstream (TRB, 2000). The interactions are dynamic in ramp influence areas. Thus any approaching expressway vehicles will tend to move right as long as there is capacity to do so. Apart from that the high intensity of ramp flow influences the behavior of expressway vehicles because the ramp volume is high on the Federal Highway Shah Alam – Kuala Lumpur.

Figure 4 indicates that there is a weak relationship between V_{12} and V_R. The rationale of this situation is because ramp demand is generated locally from the adjacent developments along the Federal Highway Shah Alam – Kuala Lumpur expressway

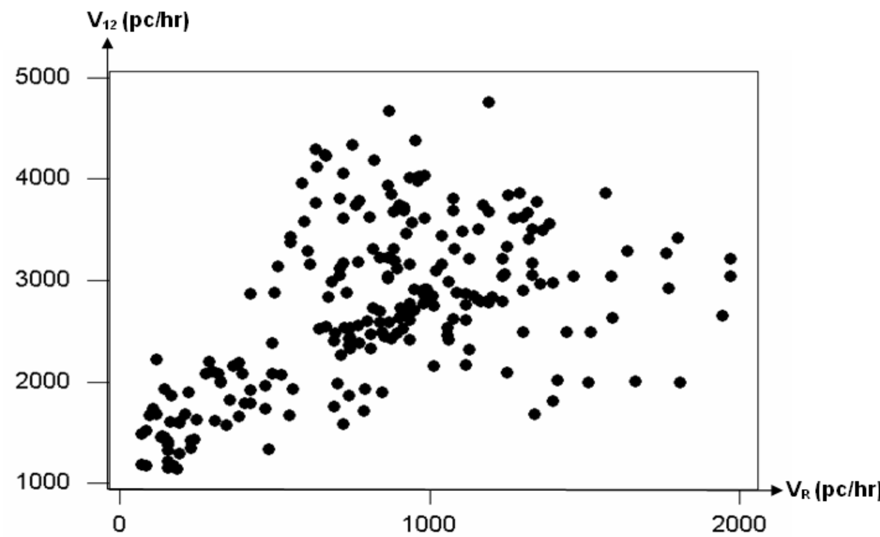

Figure 4: Measured Lane 1 and 2 Flow rates versus Ramp Flow rates

7. DEVELOPMENT OF V_{12} FLOW RATES MODEL

One of the important inputs for the basic computation order for the method for entrance ramp is to estimate flow rates V_{12} (pc/hr). The basic approach to model merge areas focuses on an influence area of 450 m including the acceleration lane and Lanes 1 and 2 of the expressway as discussed earlier. Although lane 3 may be affected by merging operations and the impact of congestion in the vicinity of a ramp can extend beyond the 450-m influence area, this defined area experiences most of the operational impacts across all levels of service (TRB, 2000). Thus, the operation of vehicles within the ramp influence area is the focus of the computational procedures. A number of variables influence the operation of ramp-expressway junctions. Among the variables affecting the V_{12} flow rates for isolated entrance ramp junctions are length of the acceleration lane L_A, total expressway flow rates V_F, and ramp flow rate V_R.

7.1 Descriptive statistics for V_{12} flow rates data

Before the reduced data could be used for analysis, data screening needs to be conducted in order to correctly identify data with errors (Norusis, 1994). Hence, histogram was generated for V_{12} flow rates as shown in Figure 5. The mean, median, maximum value, minimum value and standard deviation for parameter V_{12} flow rates are as shown in Table 1. The skewness and kurtosis values for V_{12} flow rates data in Table 2 shows the value is small thus indicating that the data is approximately normal.

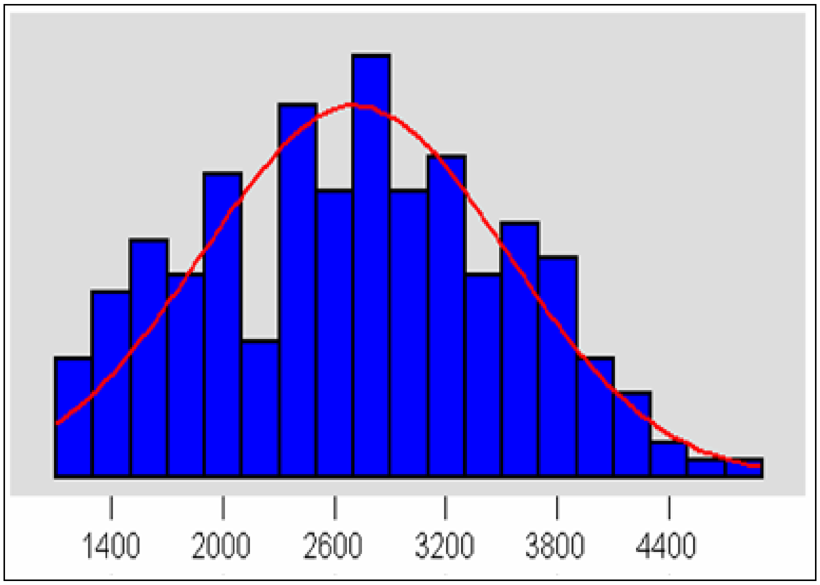

Figure 5: Histogram for Measured Flow Rates, V_{12}

Table 1: Descriptive Statistics for V_{12} flow rates

Variable	No of observation	Mean	Median	Min	Max	Standard deviation
V_{12} (pc/hr)	226	2711.3	2739.0	1140.0	4764.0	819.2

Table 2: The statistics of skewness and kurtosis for V_{12} flow rates

	Skewness	Kurtosis
V_{12}	0.0773	0.071

A number of variables influence the operation of ramp-expressway junctions. The variables affecting the V_{12} flow rates are length of the acceleration lane L_A, total expressway flow rates V_F, and ramp flow rate V_R. In order to obtain the best combination of these parameters to predict V_{12}, a stepwise regression analysis was performed. Table 3 shows the output iteration from software for forward and backward stepwise regression analysis.

Table 3: Output iteration for stepwise regression analysis for calibrating V_{12} model.

Step	**1**	**2**	**3**
Constant	169.8	175.4	398.7
V_F	0.602	0.628	0.618
T-Value	59.76	52.04	48.58
P-value	0.000	0.000	0.000
V_R	-	-0.140	-0.134
T-Value	-	-3.72	-3.60
P-Value	-	0.000	0.000
L_A	-	-	-0.929
T-Value	-	-	-2.37
P-Value	-	-	0.019
R^2	0.941	0.9444	0.946
Adj. R^2	0.940	0.9439	0.945

7.2 Stepwise Regression Methods for Modeling V_{12}

At the start of the stepwise search, V_F is entered in the model and the P-values are calculated for each potential variable mentioned earlier. The P-value for this test statistics is 0.000 and hence V_F is added to the model. At this stage, step 1 has been completed. At the bottom of column 1, a number of variables-selection criteria, including R-sq = 94.10 and R-sq (adj) = 94.07 are provided. In step 2 process, variable V_R is added to the model and the two variables are fitted. The P-value = 0.000 and the V_R can now enter the model. The column at the bottom of Step 2 in Table 3 summarizes the situation at this point. Ramp flow rate V_R and expressway flow rate V_F are added in the model. Next, all regression models containing V_F, V_R and one of the remaining potential variable L_A are fitted. In the 3rd step, the P-value = 0.019 and was next added to the model. The column labeled Step 3 in Table 3 summarizes the situation at this point. Lastly, V_F, V_R, and L_A provide the best combination set for prediction of Flow Rates V_{12}. Model in Step 3 is considered to produce the best multiple regression equation, with an R^2 value of 0.946 thus implying that 94.6% of the variation in the dependent variable is explained by the multiple regression models.

7.3 Interpretation of the Multiple Regression Statistics for V_{12} model

The results of the regression model in step 3 are studied in further detail in this section. The multiple regression equation from step 3 is as shown in equation 1.

$$V_{12} = 399 + 0.618\ V_F - 0.134\ V_R - 0.929\ L_A \quad (1)$$

Table 4 shows that V_F, V_R and L_A are very significant independent variable for predicting V_{12} where the P-value is less than 0.05, indicating that the predictor is significant and these three parameters can be included in the model for estimating V_{12}.

The results above show that the coefficient for the predictor variable V_R and L_A have a negative sign, implying that an increase in the number of ramp volume and length of acceleration lane will lead to a decrease in V_{12} flow rates. 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 values of the standard error in relation to the test coefficient, the better are the results.

Table 4: Regression Analysis for final model V_{12} versus V_F, V_R, L_A

Predictor	**Coefficient**	**Standard Error**	**T-Value**	**P-Value**
Constant	398.7	103.6	3.85	0.000
V_F	0.61750	0.01271	48.58	0.000
V_R	-0.13409	0.03725	-3.60	0.000
L_A	-0.9285	0.3924	-2.37	0.019

Analysis of variance consists of calculations that provide information about levels of variability within a regression model and form a basis for tests of significant. The analysis of variance portion of the output is as shown in Table 5 below. 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 indicates a value of 1291.01 which is less than 0.001, thus providing strong evidence against the null hypothesis (H_0 is rejected).

Table 5: Analysis of Variance for Final Model V_{12}

	DF	**SS**	**MS**	**F**	**P**
Regression	3	142797066	47599022	1291.01	0.000
Residual error	222	8185070	36870	-	-

7.4 Scatter Plot of Residuals for V_{12} model

After the fitting regression plane for V_{12} 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. The principle of regression assumes that the errors between the predicted and measured values should be normally distributed and for this reason Anderson-Darling Normality tests and Kolmogorov Smirnov test were conducted and the results are shown in Table 6. In Figure 6, the normal probability plot shows that the residuals were scattered closely to the line.

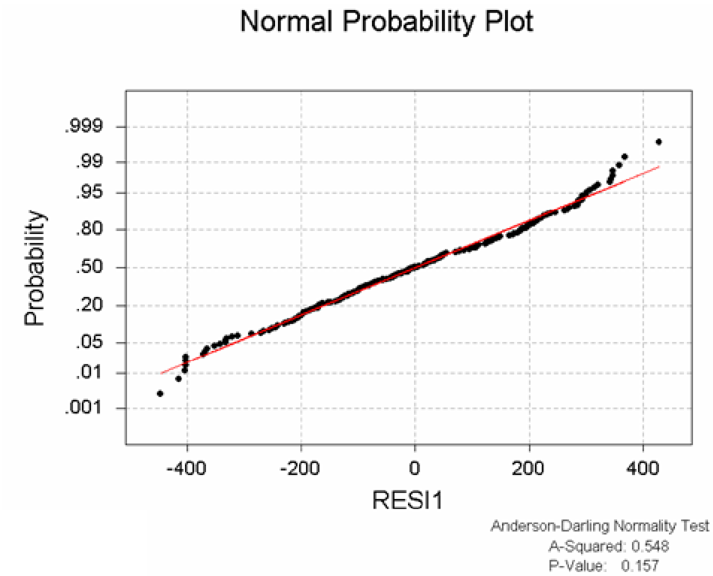

Figure 6: Normal Probability Plot of V_{12} residual based on Anderson-Darling Test

The hypothesis test for Anderson Darling Test and Kolmogorov Smirnov test can be stated as follows:

H_0 : The residuals for V_{12} model is normal
H_1 : The residuals for V_{12} model is not normal

If P-Value is greater than α=0.05, H_0 is not rejected. Referring to Table 6, since both tests produced P-value greater than α, hence the residuals are normal for final model V_{12} and hence there is no reason to doubt the validity of the regression assumptions.

Table 6: Normality Test Results

Normality Test	P-Value
Anderson-Darling Test	0.157
Kolmogorov Smirnov test	> 0.15

7.5. Verification of model V_{12}

Towards determining the LOS for entrance ramp junction, all of the developed models must be evaluated to check its ability to represent actual condition and to explain the variability present in a sample other than the one used for its calibration. Figure 7 represents the relationship between observed V_{12} and predicted V_{12} from the model proposed in this research while Figure 8 represents the relationship between observed V_{12} versus the US HCM2000 for V_{12} isolated entrance ramp model.

Note:

V_{12} measured will be denoted as $V_{12\ measured}$ (pc/hr)
V_{12} predicted using equation 1 will be denoted as V_{12} mal (pc/hr)
V_{12} predicted using HCM 2000 equation will be denoted as V_{12} US (pc/hr).

It can be seen that the data points are scattered along the linear line of the graph. This indicates that to test the validity of the developed models against the HCM 2000 model in a more precise way, the mean squared error (MSE), mean absolute error (MAE) and mean absolute percentage error (MAPE) analysis were conducted.

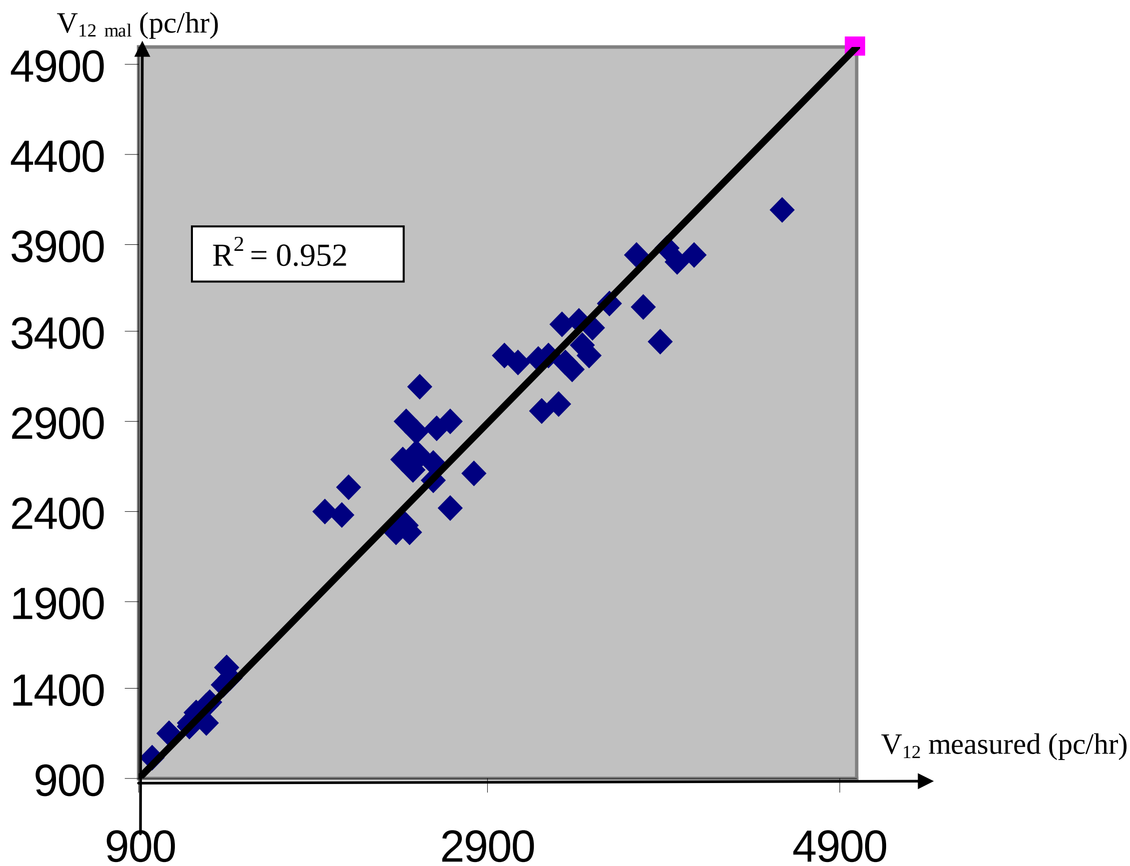

Figure 7: Predicted flow rates V_{12} from Eq. 1 versus measured V_{12} flow rates from validation database

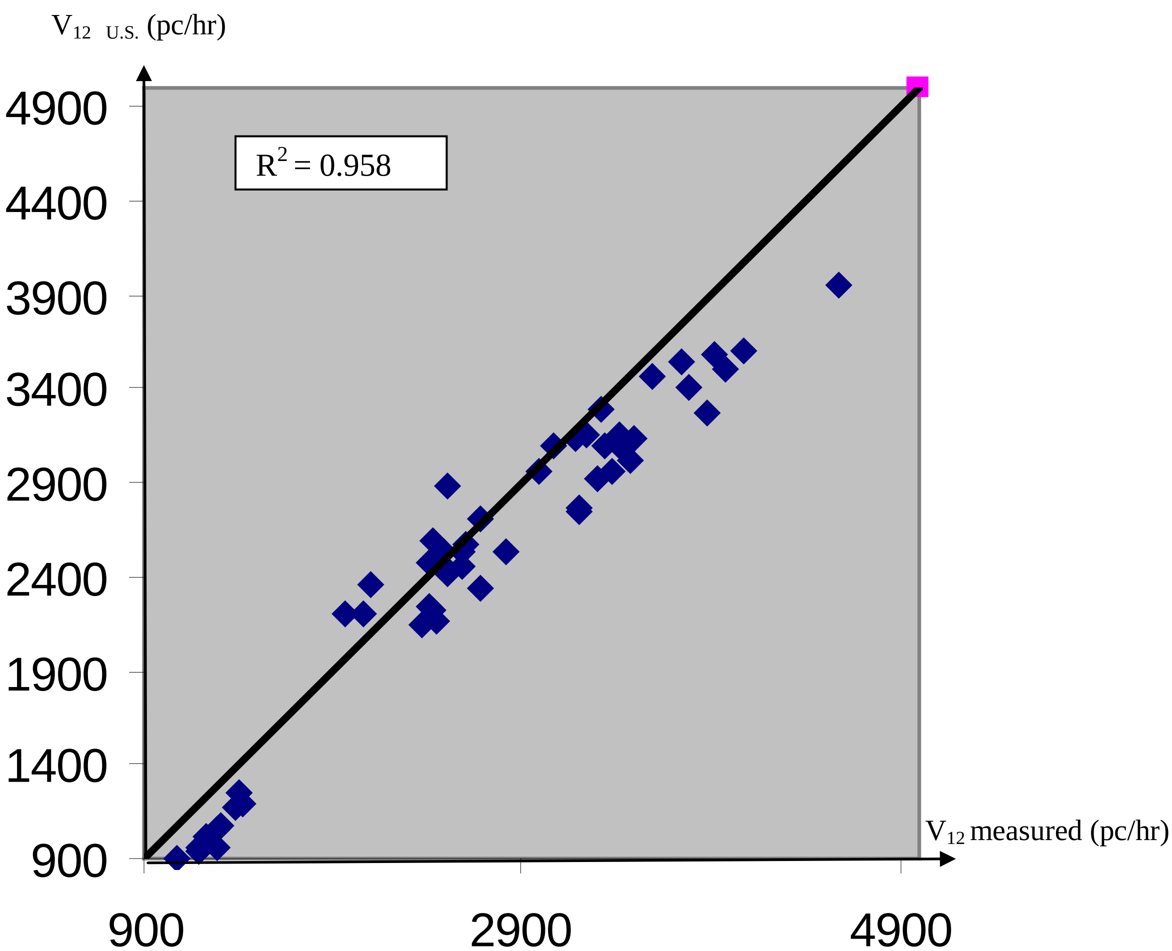

Figure 8: Predicted flow rates V_{12} from HCM 2000 versus measured V_{12} flow rates from validation database.

Table 7 below summarizes a comparison of flow rates V_{12} predicted for V_{12} mal and V_{12} US. It is indicated that the mean squared error (MSE) deviation from the empirical value of V_{12} US estimates is 74461.2pc/hr while for V_{12} mal estimates is 46682.7pc/hr. The mean absolute error (MAE) deviations from empirical value of the V_{12} US are 231.9pc/hr and for V_{12} mal is 162.9pc/hr. The mean absolute percentage error for V_{12} US and V_{12} mal from empirical value is 10.7 and 6.5 respectively. Therefore, it can be concluded that the V_{12} mal model gives closer estimates to predict flow rates V_{12} upstream of merge influences area than the V_{12} predicted using HCM 2000. The model is limited to using only for isolated on-ramp expressway junctions.

Table 7: Validation analysis results for V_{12}

Model	MSE	MAE	MAPE
V_{12} US	74461.2	231.9	10.7
V_{12} mal	46682.7	162.9	6.5

8. CONCLUSIONS

Merging flow rates linear regression model for Malaysian highway traffic have been successfully developed and validated in this study. The merging model constitutes an important aspect of expressway traffic operational analysis and ramp junction geometrical design. The US HCM 2000 model was examined in light of local empirical data. The analyses and findings concluded in this research provide extensive and valuable information to be put forward in developing the entrance ramp merging models for Malaysian Highway Capacity Manuals. Due to the fundamental differences in traffic condition, geometrical design, traffic regulation, vehicle composition and drivers' behaviors, and being a standard guide for capacity and operational analysis, there is a need then to justify the accuracy of the US HCM 2000 before being applied to other countries.

ACKNOWLEDGEMENTS

The authors wish to thank Universiti Teknologi MARA (UiTM) for being the main sponsor of this research. Appreciation goes to all individuals and organizations that have made this research possible.

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