COMPARISON OF FREE FLOW SPEED ESTIMATION MODELS

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ABSTRACT
Free flow speed (FFS) is the drivers' desired speed on roadways at low traffic volume and absence of traffic control devices whose determination is a fundamental step in the analysis of two-lane highways. FFS can either be estimated using either analytical model or based on field measurement. Regarding the former approach; the Malaysian Highway Capacity Manual (MHCM) established a model for estimating FFS based on base-free-flow-speed (BFFS), roadway's geometric features and fraction of motorcycles in the traffic stream. On the other hand, the Highway Capacity Manual (HCM) suggested an approach for field measurement of FFS; preferably at a two-way flow rate not exceeding 200 veh/h. For many highways, observing a two-way flow rate of 200 veh/h or less is seldom met or impossible. In such situations, mean speed could be observed at higher flow rates and adjusted accordingly using a model provided by the HCM. This study describes the application of the two approaches for measuring FFS. Moving car observer (MCO) method was used for collecting the relevant data related to travel time, speed, flow rate, and traffic composition with using a video recording instrumented test vehicle while the roadway geometric features were measured manually. Data for the study were collected on four directional segments of rural two-lane highways with varying geometric features and traffic composition in Johor, Malaysia. Field data obtained were analyzed to estimate the FFS using the two approaches. Results obtained from both methods were compared to ascertain the degree of their consistency or otherwise. Statistical analysis using student t-test indicates that there is no statistically significant difference between the FFS estimates from the two approaches.

Keywords: Two-lane highways, Free flow speed, Estimation, Malaysian Highway Capacity Manual, HCM

1.0 Introduction

Free-flow speed (FFS) refers to an average speed of vehicles on road segments not close to an intersection under conditions of low vehicular density. It is a significant variable used in estimating the expected operating conditions of highways, and it is only possible when the traffic volume on the road segment is below capacity. A key step in analyzing capacity and level of service for uninterrupted flow condition is the determination of free-flow speed. FFS together with demand flow rates are used in determining average travel speed of roadway facility. It has been established that various factors relating to road geometry, visibility and weather conditions influence FFS (Brilon and Ponzlet, 1996; Ibrahim and Hall, 1994; Kyte *et al.*, 2000; Medina and Tarko, 2005; TRB, 2010; Yagar and Van Aerde, 1983)

FFS can either be determined using direct field measurements or estimated using a model (TRB, 2010). Regarding the direct field measurement, the Highway Capacity Manual, (HCM

2010) (TRB, 2010) recommended that FFS can be measured directly in the field at a two-way flow arte not exceeding 200veh/h. According to the HCM, average running speed of the stream under such flow rate limit can be reported as FFS. However, for conditions where the flow rate exceeds 200veh/h, a model was established by the HCM to adjust the stream speed into a FFS; provided that the data was based on direct field measurement.

For the indirect approach, Malaysian Highway Capacity Manual (MHCM) (HPU, 2011) provides an analytical model for estimating FFS in which base-free-flow-speed (BFFS), highway's geometric features, and proportion of motorcycles were used as the model inputs.

In this study, FFS was evaluated on two-lane highways based on HCM and MHCM models at two-way flow rates higher 200veh/h on same set of roadway segments. FFS estimates from the two models were compared to ascertain their consistency or otherwise.

2.0 Experimentation

Data for this study were collected on four (4) directional segments of two-lane rural highways drawn from Pontian – Kukup (PTN – KKP) and Renggam – Kulai (REN – KUL), Johor, Malaysia. Data relating highways' geometric features, speed, and flow rates were identified as the major inputs for estimating FFS using both the HCM and MHCM models as the case may be. Inputs regarding the roadways' geometric features were measured manually using measuring tape. Speed and flow rates related parameters were collected using moving car observer (MCO) in accordance with the procedures described in the Manual of Transportation Engineering Studies (Robbertson and Findley, 2010) based on floating-car driving technique. In floating-car driving style, the test vehicle is driven into the traffic stream under study and overtakes as many vehicles as overtaking it; through this, the test car estimates the behaviour of an average vehicle in the traffic stream (Roger *et al.*, 2004). The speed of the test vehicle is thus regarded as the average speed of the traffic stream evaluated.

In applying the MCO method, a segment length of 3.50 km was used for the data collection by performing six (6) test runs on each directional segment; as six runs were found to be satisfactory for consistent and unbiased estimates of measured variables (Mortimer, 1957). A passenger car equipped with video recording system was used as the test vehicle. The video recording system captures real time traffic events over the entire period of the test runs and stores the recorded traffic events onto an SD memory card inserted into the recorder and subsequently uploaded to computer for processing. The recorded traffic events were then played back in a computer to extract the required data. During the playback, the time taken to traverse the study segment was noted while the numbers of vehicles against the test car travel direction, vehicles overtaking the test car and vehicles passed by the test car were extracted respectively. The hourly flow rates for northbound and southbound directions were determined using equations (1) and (2), respectively.

$$V_n = \frac{60(M_s + O_n - P_n)}{(T_s + T_n)} \quad (1)$$

$$V_s = \frac{60(M_n + O_s - P_s)}{(T_n + T_s)} \quad (2)$$

Where,

V = Directional hourly volume (veh/h)

M = Opposing vehicles to the test car's direction of travel (veh)

O = Vehicles overtaking the test car (veh)

P = Vehicles passed by the test car (veh)

T = Directional travel time taken to traverse the study segment (minutes)

The subscripts n and s refer to northbound and southbound directions, respectively.

2.1 HCM Adjustment Model for FFS Estimation

Based on the HCM, for speed study conducted at a two-way flow rate of more than 200 veh/h, a volume adjustment must be made in order to determine FFS. Equation (3) was provided by the HCM for making the adjustment.

$$FFS = S_{FM} + 0.00776\frac{V_f}{f_{HV}} \tag{3}$$

Where,

FFS = Estimated Free-Flow Speed (km/h)

S_{FM} = Mean Speed of traffic measured in the field (km/h)

V_f = Observed flow rate for the period when field data were obtained (veh/h)

f_{HV} = Heavy-vehicle adjustment factor, computed using equation (4)

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \tag{4}$$

Where,

P_T = Proportion of trucks in the traffic stream, expressed as a decimal

P_R = Proportion of recreational vehicles (RVs) in the traffic stream, expressed as a decimal

E_T = Passenger-car equivalent for trucks

E_R = Passenger-car equivalent for RVs

Mean speed of traffic stream was obtained by taking the ratio of the segment length to the travel time taken to traverse the study segment. Directional traffic flow rates and composition of heavy traffic (trucks) was extracted from the field recorded data using the MCO method. Heavy vehicles adjustment factors were obtained from tables provided by the HCM.

2.1 MHCM Model for FFS Estimation

The MHCM provided an FFS estimation model for two-lane highways, based on BFFS, adjustment for the effect of lane and shoulder widths narrower than 3.65 m and 1.80 m respectively as well as the effect of proportion of motorcycles in the traffic stream. Equation (5) shows the MHCM model in which a BFFS value of 90 km/h was recommended.

$$FFS = BFFS - f_{LS} - f_{APD} - f_m \tag{5}$$

Where,

FFS = Free-Flow Speed (km/h)

BFFS = Base Free-Flow Speed (km/h)

f_{LS} = Adjustment for lane and shoulder widths less than 3.65 m and 1.80 m, respectively (km/h)

f_{APD} = Adjustment for access points density (km/h)

f_m = Adjustment for proportion of motorcycles (km/h)

3.0 Results and Discussions

3.1 Geometry of the study segments

As stated earlier, four directional segments were chosen for this study. For each of the segments, data were collected and reported as northbound (NB) or southbound (SB) directions depending on the segments. Table 1 presents the geometric features of the segments used in this study which are parts of the required inputs in estimating FFS using MHCM model.

Table 1: Roadways Geometry

Road	Direction	L_w (m)	SH_w (m)	APD (access/km)
PTN – KKP	NB	3.09	0.25	1.71
	SB	3.09	0.26	1.71
REN - KUL	NB	3.65	1.50	0.29
	SB	3.65	1.60	0.29

L_w = Lane width, SH_w = Shoulder width, APD Access point density

3.2 Free Flow Speed Estimation

Free flow speeds were estimated on the selected two-lane highway segments using both the HCM and MHCM as described in the subsequent sections. FFS estimates from the two models were also compared.

3.2.1 FFS Estimation Using HCM Adjustment Model

Equations (3) and (4) were used for the estimation of FFS in this case. Directional mean speeds of the segments were first obtained using MCO after which the directional traffic volumes were determined alongside with the proportion of trucks for each direction. Exhibits presented in HCM were used for the determination of passenger car equivalents (PCE) for trucks used in equation (4) for the determination of heavy-vehicle adjustment factor. Trucks were the only type of heavy vehicle for Malaysian traffic condition, as such recreational vehicles (RV) were not considered in the analysis. Table 2 shows the flow rates, mean speeds, heavy-vehicle adjustment factors, as well as the estimated FFS for the four directional segments.

Table 2: FFS Using HCM Adjustment Model

Road	Direction	q (veh/h)	Travel time (min)	Mean Speed (km/h)	P_T	PCE	f_{HV}	FFS (km/h)
PTN – KKP	NB	299	2.82	74.42	0.08	1.40	0.97	76.82
	SB	195	2.74	76.60	0.03	1.50	0.98	78.13
REN - KUL	NB	164	2.40	87.62	0.07	1.60	0.96	88.95
	SB	259	2.40	87.44	0.05	1.40	0.98	89.49

q = average directional flow rate, P_T = proportion of trucks

3.2.2 FFS Estimation Using MHCM Adjustment Model

Equation (5) was used for the determination of the FFS and the estimates are as shown in Table 3. All adjustment factors were obtained from tables provided by the MHCM.

Table 3 FFS Using MHCM Estimation Model

Road	Direction	q (veh/h)	PMc (%)	f_{LS} (km/h)	f_{APD} (km/h)	f_m (km/h)	FFS (km/h)
PTN – KKP	NB	299	0.26	7.80	2.04	2.60	77.56
	SB	195	0.09	7.80	2.04	1.70	78.46
REN - KUL	NB	164	0.06	1.00	0.35	0.78	87.87
	SB	259	0.06	0.70	0.35	0.78	88.17

$FFS = 90 - f_{LS} - f_{APD} - f_m$, PMc = Proportion of motorcycles

3.3 Comparison of the two FSS Estimation Models

Table 3 presents a summary of the FFS estimates obtained from HCM and MHCM models for ease of comparison.

Table 4: Comparison of FFS Estimation Models

Road	Direction	FFS_{HCM} (km/h)	FFS_{MHCM} (km/h)
PTN – KKP	NB	76.82	77.56
	SB	78.13	78.46
REN - KUL	NB	88.95	87.87
	SB	89.49	88.17
Mean values (km/h)		83.35	83.02

FFS estimates from the two models seem to differ slightly. However, while for PTN – KKP segment FFS values based on HCM model were slightly lower than those from MHCM model; in the case of REN – KUL segment, an opposite of that recorded. This indicates that estimates from the two approaches do not follow a particular pattern. Based on the irregular trend shown by the FFS estimates from the two models, a more reasonable comparison could be drawn using the mean FFS values. On the basis of the mean FFS values, the two models resulted in consistent estimates even though, MHCM estimates were lower than HCM values by about 0.4%. This difference could be deemed negligible enough that may not cause any considerable effect. To ascertain the extent of the effect of this difference could cause if any, a statistical analysis using t-test at 95% confidence level was carried out to find out whether the difference between the means of the FFS is significant.

Results from the statistical analysis revealed that there is statistically significant difference between the two sets of data as p- value (0.5610) is far greater than 0.05. This finding suggests that either of the equations can be used to estimate FFS on two-lane highways.

4.0 Conclusion

Free-flow-speed is an essential parameter in the capacity and level of service analyses for two-lane highways. It is estimated either through direct field measurement at two-way flow rate not exceeding 200 veh/h or indirectly using analytical model. Direct field measurement of FFS is seldom realistic as roadways mostly operate at flow rates higher than the specified level. This made it necessary to utilize analytical models alongside with some adjustments to estimate FFS. The current study presented an evaluation of FFS on two-lane highways based on the indirect measuring approach using HCM and MHCM models. Results obtained from the two approaches were compared to establish their consistency or otherwise. Findings from statistical analysis using t-statics revealed that there is no statistically significant difference between the two data sets as p – value (0.5610) is far greater than 0.05. A key implication of this finding is that either of the models can be used for indirect estimate of FFS; especially for situations where the combined directional flow rates exceed the minimum specified.

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