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Application of Moving Car Observer Method for Measuring Free Flow Speed on Two-lane Highways

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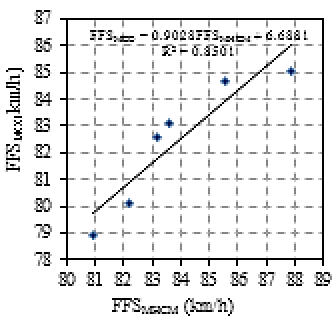
Graphical abstract



Abstract

There exists a need to evaluate the performance indicator that reflects the current level of service (LOS) of the subject facility to justify any decision making on expenditures to be made for improving the performance level of a road facility. Free-flow speed (FFS) is one of the key parameters associated with LOS assessment for two-lane highways. Application of a more realistic approach for assessing road's performance indicators would result in better estimates which could in turn suggest the most appropriate decision to be made (for situations where upgrading is needed); especially, in terms of finance, materials and human resources. FFS is the driver's desired speed at low traffic volume condition and in the absence of traffic control devices. Its estimation is significant in the analysis of two-lane highways through which average travel speed (ATS); an LOS indicator for the subject road class is determined. The Highway Capacity Manual (HCM) 2010 offers an indirect method for field estimation of FSS based on the highway operating conditions in terms of base-free-flow-speed (BFFS). It is however, recommended by the same manual that direct field FSS measurement approach is most preferred. The Malaysian Highway Capacity Manual (MHCM) established a model for estimating FFS based on BFFS, the geometric features of the highway and proportion of motorcycles in the traffic stream. Estimating FFS based on BFFS is regarded as an indirect approach which is only resorted to, if direct field measurement proved difficult or not feasible. This paper presents the application of moving car observer (MCO) method for direct field measurement of FFS. Data for the study were collected on six segments of two-lane highways with varying geometric features. FFS estimates from MCO method were compared with those based on MHCM model. Findings from the study revealed that FFS values from MCO method seem to be consistently lower than those based on MHCM model. To ascertain the extent of the difference between the FFS values from the two approaches, student t-statistics was used. The t-statistics revealed a P–value of less than 0.05 ($P < 0.05$) which implies that there is a statistically significant difference between the two sets of data. Since MCO method was conducted under low traffic flow (most desired condition for field observation), it can be suggested that MCO estimates of FFS represent the actual scenario. A relationship was therefore developed between the estimates from the two methods. Thus, if the MHCM model is to be applied, the measured value needs to be adjusted based on the relationship developed between the two approaches.

Keywords: Two-lane highways; free flow speed; HCM; Malaysian Highway Capacity Manual; moving car observer method

■1.0 INTRODUCTION

Free flow speed (FFS) is referred to as a motorist's desired speed on a road segment at low traffic flow or low traffic density condition, and in the absence of traffic control devices. It is a significant variable used in assessing the expected operating conditions or level of service (LOS) of highways. A key step in the capacity and LOS analyses of two-lane highways is the determination of FFS through which average travel speed (ATS), a key LOS indicator for the subject road class is estimated. The Highway Capacity Manual 2010 (HCM 2010) suggests an indirect method for field measurement of FSS based on the operating conditions of the highway in terms of base-free-flow-speed (BFFS) and geometric features regarded as factors influencing FFS [1-3]. It is however, recommended by the HCM 2010 that direct field measurement of FSS is the most preferred approach. Other sources suggested that FFS be measured as the mean speeds of unimpeded vehicles traveling with headways greater than 8 seconds based on spot observation [4, 5].

For many applications, FFS is measured using the indirect method suggested by HCM or mean speeds of vehicles traveling with headways larger than 8 seconds at a particular point. Malaysia is one of the countries that practice the application of the indirect method for estimating FFS as reported in the Malaysian

Highway Capacity Manual (MHCM) [6]. The MHCM established a model for estimating FFS on two-lane highways based on BFFS, highway's geometric features and proportion of motorcycles in traffic stream. Estimation of FFS based on BFFS is regarded as an indirect approach which is only resorted to if direct field measurement proved difficult or not feasible. Likewise, the use of mean speeds of unimpeded vehicles traveling with headways larger than 8 seconds for estimating FFS is specific point biased and may not accurately account for the effects of variations in operational conditions and geometry along the road segment. Thus, estimates of FFS; a key step in LOS analysis of two-lane highways from these approaches could be misleading regarding a decision making on expenditure for highway improvement.

To justify a decision making on any expenditure to be made for improving the performance level of road facility, it is therefore, desirable to evaluate the performance indicator that reflects the current LOS using the most appropriate approaches. Application of a more realistic approach for assessing road's performance indicators would results in better estimates which will in turn suggests the most suitable decision to be made (for situations where upgrading is needed); especially, in terms of finance, materials, human resources and so on. It is therefore, essential to employ the most appropriate technique for field measurement of FFS; especially, one that would evaluate the parameter along road segment instead of applying an indirect approach or spot observation, both of which are either based on user judgement or specific point values that may not truly reflect the performance of the segment.

This paper presents the application of moving car observer (MCO) method for direct field measurement of FFS under low traffic flow condition; being the most preferred approach. FFS was also estimated based on the MHCM model and the results from the two approaches compared.

■2.0 EXPERIMENTAL PROCEDURE

A total of six segments of two-lane highways were chosen for this study. Sites for the study were selected based on the following criteria:

i. All segments representing the road were demarcated far away from intersections that can influence traffic flow.
ii. Segments with varying geometric features were selected thereby obtaining reliable data that has no limitations due to geometric features.
iii. Segments with varying traffic flow and composition were used to enable a wide range of confidence in the outcome.

The study sites used for the data collection are; two segments from each of Kulai – Kota Tinggi (KUL-KTG), Kampung Sungai Tiram – Ulu Tiram (KST-UTR), and Mersing – Endau (MRS-END) segments, all in Johor, Malaysia. Data on the required inputs for estimating FFS using both MCO method and MHCM model were collected on the chosen road segments.

2.1 Measuring FFS Using Moving Car Observer Method

MCO is a method that involves the use of test vehicle within a traffic stream for measuring travel time, flow rate, speed, and delay over a roadway segment. The method has been described as quite efficient and practical for estimating these variables [7]. Data for estimating FFS in this study using the MCO method were collected in accordance with the procedures presented in the Manual of Transportation Engineering Studies based on 'floating car technique' driving approach [8]. In this technique, the driver of the test car drives into the traffic stream to be evaluated and overtakes as many vehicles as overtake the test vehicle along the road segment as passing opportunities permit. By so doing, the test vehicle approximates the behaviour of an average vehicle in the traffic stream and is generally applied only on two-lane highways [9]. Consequently, the speed of the test vehicle is considered as the average speed (FFS) of all vehicles in the traffic stream.

To conform to the specifications for direct field measurement of FFS at low traffic flow condition; i.e. at two-way flow rate of 200 veh/h or less [1], off-peak periods were used for the data collection on all the segments. Similarly, all the data were collected during daylight period and good weather condition in order to avoid the influence of factors affecting free-flow speed as reported in previous studies [3, 10-13].

A segment length of 3.5 km was used for the data collection by making six (6) test runs in each traffic direction. Performing 6 test runs per traffic direction was demonstrated as sufficient for consistent and unbiased estimates of measured variables [14]. A passenger car instrumented with Video Velocity VBox (VBox) was used as the test vehicle. A VBox is an on-board video data recording system comprising of video camera, GPS, and SD memory card. The camera attached to the VBox (powered using the vehicle cigar plug) and fixed on the test car's front windscreen records the traffic event of the road under study. The system automatically stores the recorded traffic events onto the memory card inserted into the VBox and later uploaded to computer for processing. The recorded information was then played back to extract the required data for the analysis. During the playback, the time taken to traverse the study segment was noted while the numbers of opposing vehicles to the direction of travel, vehicles overtaking the test car and vehicles passed by the test car were counted. 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 for the north-bound direction (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 = Travel time taken to traverse study segment (minutes)

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

The average free-flow speed for each direction is estimated as the ratio of the segment length and total travel time taken to traverse the segment.

2.2 Measuring FFS Using Malaysian Highway Capacity Manual Model

The MHCM provided a model for estimating FFS based on base-free-flow-speed (BFFS) along with some adjustments based on road conditions and traffic characteristics for Malaysian condition as shown in Equation (3):

$$FFS = BFFS - f_{LS} - f_{APD} - f_m \quad (3)$$

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)

The MHCM recommended a BFFS of 90 km/h for Malaysian two-lane highways. Lane and shoulder widths were measured manually using a measuring tape while the access points over the chosen segments were counted and their densities relative to the segment length determined. Adjustments for the effects of the variables in Equation (3) were obtained from tables provided by the MHCM [6]. Using Equation (3), the directional FFS for each segment was estimated.

3.0 RESULTS AND DISCUSSIONS

3.1 Geometry of Roads Segments Studied

For each of the roads chosen in this study, the geometric features of the directional segments; designated as northbound (NB) and southbound (SB) were evaluated as presented in Table 1.

Table 1 Roadways geometry

Road	Direction	L_w (m)	SH_w (m)	APD (access/km)
KUL - KTG	NB	3.40	1.00	0.29
	SB	3.40	1.20	0.29
KST - UTR	NB	3.15	0.30	0.00
	SB	3.15	0.10	0.00
MRS - END	NB	3.30	2.00	0.00
	SB	3.40	2.20	0.00

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

3.2 Estimation of Free-flow Speed

As mentioned in the preceding sections, free-flow speed was estimated in this study using MCO and MHCM model approaches. The following subsections present the summary of the FFS estimates using the two approaches.

3.2.1 FFS Estimates Using Moving Car Observer Method

Equations (1) and (2) were used to determine the directional flow rates for the northbound and southbound segments from which the two-way hourly flow rate for each segment was determined. This is to ensure that FFS is estimated at the specified two-way flow rates of 200 vehicles per hour or less. FFS was determined as the ratio of the segment length and average travel time taken (for the six test runs) to traverse the study section. Table 2 presents the results of the FFS estimates for the six studied directional segments.

Table 2 Free flow speed using moving car observer method

Road	Direction	q (veh/h)	T (mins)	FFS (km/h)	FFS_m (km/h)
KUL - KTG	NB	77	2.53	83.11	82.87
	SB	77	2.54	82.62	
KST - UTR	NB	97	2.62	80.15	79.55
	SB	55	2.66	78.95	
MRS - END	NB	77	2.48	84.68	84.85
	SB	36	2.47	85.02	

q = Flow rate, T = Mean travel time, FFS_m = Mean FFS

The FFS estimates for the six directional segments presented in Table 2 indicated that MRS – END segment recorded the highest directional values as well as the mean value. This could be due to its relative wide lane and widest shoulder as compared to other cases as these features improve visibility and ease of manoeuvre within the traffic stream and could in turn allow for higher travel speed. One other factor attributed to the highest FFS for MRS – END segment is its low flow rate. In fact, it has lowest two-way traffic flow compared to others during which the observations were made. On the other hand, KST – UTR segment recorded the lowest FFS values. Its least FFS values are consistent with its geometric features and flow rate; that is narrowest lane and shoulders, and relative high traffic volume. FFS values for KUL – KTG segment lies between those of MRS – END and KST – UTR segments which also seem to be consistent with the road geometry and flow rate. Despite the wide lane of KUL – KTG segment, its low FFS value when compared to that of MRS – END might be due its narrow shoulder width, higher two-way flow rate and presence of an access point, all of which are regarded of having a reduction effect on FFS.

3.2.2 FFS Estimates Using Malaysian Highway Capacity Manual Model

Table 3 presents the FFS estimates based on MHCM model as given by Equation (3). FFS was estimated based on base-free-flow-speed (BFFS) and adjustments for the effect of road geometric features and traffic characteristics. The model recommends a BFFS of 90 km/h while adjustments for the effects FFS influencing factors (lane and shoulder widths, access point density and proportion of motorcycles in the traffic stream) were determined from Tables provided by the MHCM [6]. The directional free-flow speeds for all the segments were determined as well the mean value for each pair of directions as presented in Table 3.

Table 3 Free flow speed using MHCM model approach

, P

Road	Direction	q (veh/h)	PMc (%)	f_{ls} (km/h)	f_{APD} (km/h)	f_m (km/h)	FFS (km/h)	FFS_m (km/h)
KUL - KTG	NB	79	17	1.50	0.35	2.14	83.61	83.39
	SB	79	26	1.30	0.35	3.28	83.17	
KST - UTR	NB	97	3	7.42	0.00	0.39	82.19	81.57
	SB	55	10	7.75	0.00	1.30	80.95	
MRS - END	NB	77	22	1.70	0.00	2.76	85.54	86.72
	SB	36	7	1.20	0.00	0.91	87.89	

$FFS = 90 - f_{LS} - f_{APD} - f_m$ Mc = Proportion of motorcycles, other variables were described earlier

Estimated FFS values (Table 3) from this approach were found to be consistent with trend exhibited by MCO method. MRS – END segment recorded the highest FFS followed by KUL – KTG segment with KST – UTR having the least FFS value. Trends exhibited by these results (based on MHCM model) are well consistent with those based on MCO method. This could also be as result of the variation in the segments' geometric features and traffic characteristics as described in the preceding section.

3.2.3 Comparison of FFS Estimates from MCO and MHCM Model Approaches

To explicitly show the relationship between the FFS estimates from the two approaches, a comparison was made based on the results obtained as presented in Table 4.

Table 4 Comparison of FFS estimates

Road	Direction	FFS_{MCO} (km/h)	FFS_{MHCM} (km/h)
KUL - KTG	NB	83.11	83.61
	SB	82.62	83.17
KST - UTR	NB	80.15	82.19
	SB	78.95	80.95
MRS – END	NB	84.68	85.54
	SB	85.02	87.89
Mean Values		82.42	83.89

The results presented in Table 4 indicated that observed FFS estimates from MCO method were found to be consistently lower that those based on MHCM model. This is well consistent with the overall mean FFS value for all the segments evaluated. This could be due to the fact that FFS estimates from MCO method were based on spatial measurement as such estimates from that are usually expected to account for the effects of other vehicles' speeds in the traffic stream and perhaps, the low value compared to the MHCM model which is based on fixed value of BFFS.

To examine the extent of the difference between the FFS values from the two approaches, further comparison among the estimates was made based on 45° diagonal line plot to see how the data points are scattered relative to the diagonal line as is illustrated in Figure 1.

From Figure 1, it could be seen that all the data points lie below the 45° diagonal line which indicates that MHCM are consistently higher than those based on MCO. MHCM model estimates were found to be higher by about 1.5 km/h (based on the overall mean FFS values). In other words, FFS estimates from MHCM seem not to represent the actual FFS as values obtained using MCO method were observed under low flow rate being the most preferred measuring condition for field estimation of FFS.

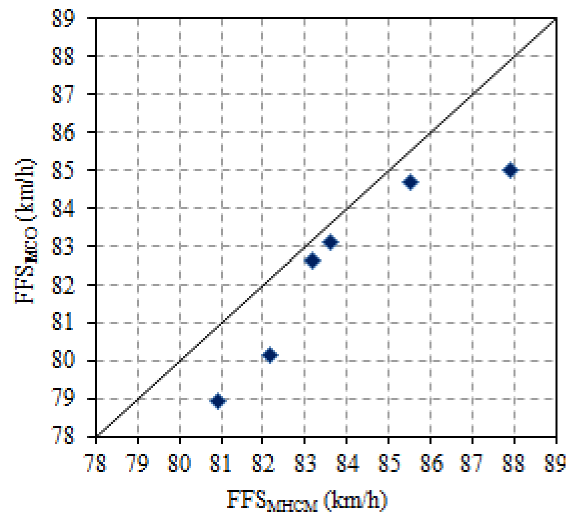


Figure 1 Comparison between FFSMCO and FFSMHCM

In addition to the comparison between the FFS values from the two approaches, a relationship was also developed between them that would enable the prediction of FFS from one method using the other. Figure 2 shows the graphical relation between the FFS values from the two approaches while Equation 4 gives the mathematical form of the relationship.

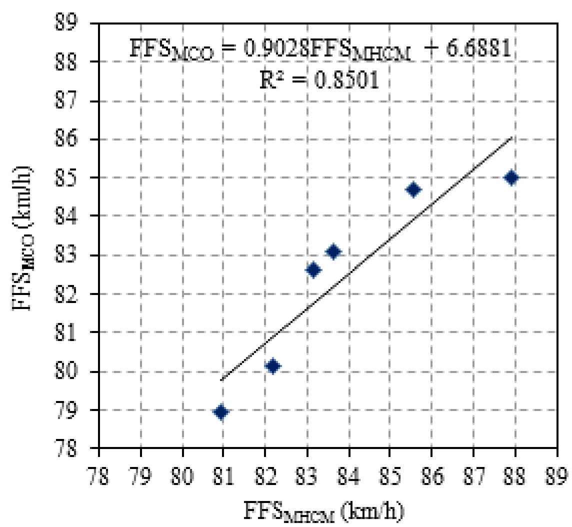


Figure 2 Relationship between FFS_{MCO} and FFS_{MHCM}

$$FFS = 0.9028 FFS_{MHCM} + 6.6881, \quad R^2 = 0.8501 \quad (4)$$

where,
FFS_{MCO} = Free-flow speed from moving car observer method
FFS_{MHCM} = Free-flow speed from Malaysian highway capacity manual model

Thus, finding from this study suggests that FFS estimates recorded using MCO represent the actual values except proved otherwise using statistical analysis. Because, FFS estimates from MCO method were observed under the most desired field measuring condition (at low rate; not exceeding 200 veh/h in both directions). However, if there is no statistical significant difference between the estimates from the two approaches; either could be applied to estimate FFS. To establish the difference, a statistical analysis using student t-statistics was carried out. Prior to the conduction of the test, normal probability test was carried out to check whether the observed data is normally distributed or otherwise. Results from the normality test revealed that the observed data were normally distributed as data points were found to fall around the normal probability line.

Further analysis using the t-test at 95% confidence level revealed a p–value less than 0.05 ($p < 0.05$). This implies that there is a statistically, significant difference between the two sets of data. Since MCO method was conducted under very low traffic flow, it can be claimed that MCO estimates of FFS represent the actual scenario. Therefore, if the MHCM model is to be applied, resulting values need to be adjusted using Equation (4).

■4.0 CONCLUSIONS

Free flow speed (FFS) is a significant parameter in the capacity and level of service analyses of two-lane highways. In estimating FFS for such applications, it was suggested that direct field measurement of the parameter is the most preferred approach for more realistic results. However, for various traffic engineering applications, FFS is estimated using an indirect measurement method based on base-free-flow-speed (BFFS) and highway's operating conditions; an approach suggested as an alternative only if direct field measurement proved difficult or not feasible. This study presented the feasibility of using moving car observer (MCO) method for direct field measurement of FFS. An indirect method for measuring FFS based on Malaysian Highway Capacity Manual (MHCM) model was also evaluated. Results from the two approaches were compared and a relationship between them developed. Findings from the study revealed that FFS values based on MHCM model were found to be consistently (slightly) higher than those based on MCO method. MHCM model estimates were on the higher side by about 1.5 km/h (based on the overall mean FFS values from the approaches). To ascertain the extent of the difference between the FFS values from the two approaches, a statistical analysis was carried out using student t-statistics. The t-statistics revealed a P – value of less than 0.05 ($P < 0.05$) which implies that there is a statistically significant difference between the two sets of data. Since MCO method was conducted under low traffic flow (most desired condition for field observation), it can be suggested that MCO estimates of FFS represent the actual scenario. A relationship was therefore developed between the estimates from two approaches. Thus, if the MHCM model is to be used, the value need to be adjusted based on the relationship developed between the two approaches.

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