SPEED–FLOW RELATIONSHIP FOR TWO–LANE SINGLE CARRIAGEWAY ROAD

Othman Che Puan, Nur Syahriza Muhamad Nor, Nordiana Mashros

Faculty of Civil Engineering, Universiti Teknologi Malaysia

othmancp@utm.my, nursyahriza@gmail.com, mnordiana@utm.my

ABSTRACT Speed–flow relationship is one of the main information used in the road performance and capacity analysis. The development of the speed–flow relationship for Malaysian two–lane two–way highways, as established in Malaysian Highway Capacity Manual 2011, was based on the U.S. Highway Capacity Manual 2000 methodology. This paper presents the preliminary result of a study carried out to evaluate the speed–flow relationship trend on various road segments. Five uninterrupted two–lane single carriageway road segments located in different regions of Malaysia were considered in the analysis. Data pertaining to the speed-flow analysis was collected using an automatic traffic counter. The trends of the speed–flow variations did not seemed to follow the traditional shape of the speed–flow relationship. Flow breakdowns were not observed even when the total flow rate was more than 1,800 veh/h. The MHCM 2011 speed–flow model produced significantly higher estimates of speed compared with the observed data. The USHCM 2010 speed–flow model, on the other hand, only in a good agreement with speed–flow data for roads with a posted speed limit of 70 km/h or higher. More data representing large range of traffic flow conditions and road alignments are required to validate such findings and hence to determine the capacity of a two–lane two–way highway to be applied in the road performance analysis.

1. INTRODUCTION

Highway capacity can be interpreted in many ways. However, the general definition as given by the American Transportation Research Board (TRB, 2010), is, "the maximum number of vehicles that can pass a given point during a specified period under prevailing roadway, traffic, and control condition".

The earlier version of USHCM (TRB, 2000) stated that, "capacity normally refers to a point or uniform segment of the facility. Capacity analysis is conducted for segments of a facility having uniform traffic, roadway, and control conditions. Because capacity depends on these factors, segments with different prevailing conditions will have different capacities. The point or segment with the poorest operating conditions often determines the overall level of service for the facility."

In general, highway capacity is often inferred from speed–flow–density relationships (Minderhoud, et al., 1997). This paper discusses speed–flow relationships based on USHCM 2010 and MHCM 2011 methodologies and evaluates their fitness with the observed data.

The speed–flow–density relationships, as they are traditionally understood, are in a parabolic form as described by many researchers (Garber and Hoel, 2001, Heydecker and Addison, 2011). However, the speed–flow relationship proposed by TRB (2000) as shown in Figure 1 does not seem to fit the traditional form of the relationship. The Malaysian Highway Planning Unit (2011) later has established speed-flow relationship in the MHCM 2011 which is also not in a parabolic-formed of relationship as expected (see Figure 2).

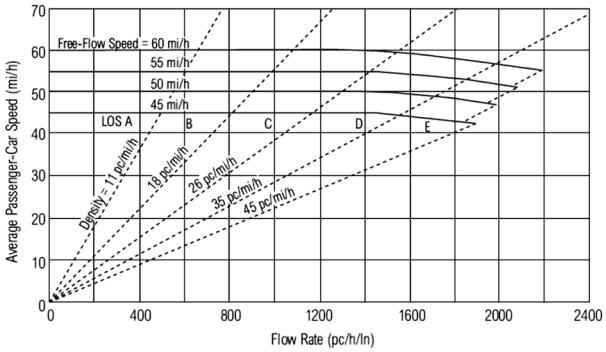

Fig. 1 Relationship average travel speed with flow rate (TRB, 2000)

In the recent USHCM 2010 (TRB, 2010), the speed–flow relationship for a two-way two-lane highway was further revised as shown in Figure 3. It can be seen from Figure 3 that the highest intercept or free-flow speed, u_f has increased from 60 mph (96.6 km/h) to 75 mph (120.7 km/h).

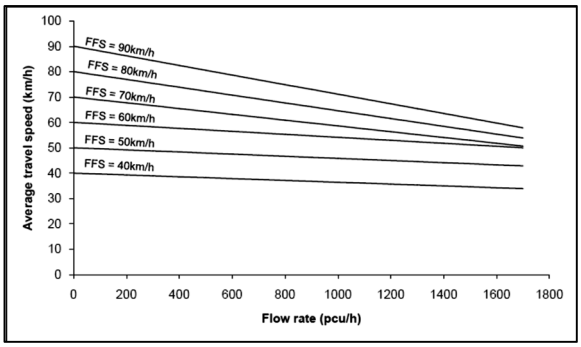

Fig. 2 Relationship average travel speed with flow rate (HPU, 2011)

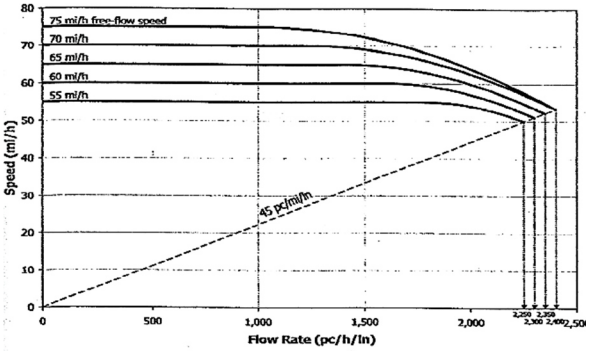

Fig. 3 Relationship speed with flow rate (TRB, 2010)

2. METHODOLOGY

2.1 Site Selection

Five uninterrupted two–lane single carriageway road segments were considered in the analysis. Each of the selected segments is located on the federal or state road. The names of the road segments and locations are summarised in Table 1. In order to ensure that there is no interruption on the speed behaviour and the motorist's selected speed is in a stable condition, the selection of survey sites was based on the following criteria (Leong and Awang, 2011) and (Lee and Brocklebank, 1993):

i. Homogeneity: Segment is relatively homogeneous in geometric characteristics.
ii. Junctions: There is no major junction within the segment or within at least 1km of its endpoints.
iii. Road works: There is no road works were taking place along the segment.
iv. Length: Segment is more than 2 km and not greater than 5 km in length.

Table 1 Site location

Site no.	Site ID	Location
1.	J/J46/1A	Ulu Choh, Johor
2.	C/FT003/1A	Cherating, Pahang
3.	J/FT003/1A	Kota Tinggi, Johor
4.	P/P145/1A	Valdor, Pulau Pinang
5.	S/SA2/1B	Kinarut, Sabah

2.2 Data Collection and Analysis Method

The general characteristics of each of the road segments at which the traffic data was collected are tabulated in Table 2. Data pertaining to the speed and flow analysis was collected using an automatic traffic counter (ATC). An ATC allows traffic data to be collected for a long period of time.

Table 2 Site characteristics

Site no.	Both lane width, m	Shoulder, m		Verge, m		Posted speed limit	Alignment
		AB	BA	AB	BA		
1.	7.00	1.00	1.00	3.00	3.00	60	Straight & Flat
2.	7.00	2.50	2.50	6.00	4.50	70	Straight & Flat
3.	7.30	0.70	0.70	4.00	4.50	90	Straight & Flat
4.	7.00	0.15	0.00	3.00	2.50	60	Straight & Flat
5.	6.50	0.00	0.00	1.60	2.60	60	Straight & Flat

For this study, spot speed and traffic volume data were collected for a period of 24 hours to get the stratification of the sample. The hourly speed and flow data for each site were extracted from the ATC and were further subdivided into a 15–minute interval datasets. This is to capture various moment if there are any platooning situation occurred in the segment (Minderhoud, et al., 1997). The traffic volume for 15 minutes interval were multiplied by 4 to give a flow rate in veh/h (TRB 2010). The average spot speed or time mean speed were then converted to space mean speed using Equation 1 (HPU, 2011, Leong and Awang, 2011).

$$u_s = 1.016u_t - 1.704 \quad (1)$$

where u_s is space mean speed while u_t is time mean speed.

3. RESULTS AND DISCUSSION

3.1 Data description

Data extracted from ATC for each site shows a relatively large variations of hourly traffic volume, spot speed, flow rate and space mean speed data. There are 96 datasets for each site. Table 3 tabulates the summary of traffic characteristics at each of the sites. It can be seen from Table 3 that in general the spot speeds of vehicles observed at all sites were in the range of 10 km/h to 157 km/h. The space mean speeds were in the range of 47.27 km/h to 94.44 km/h. The highest volume of traffic of 1658 veh/h was recorded at site ID J/J46/1A. The total 24–hour traffic volumes at all sites were in range of 10,290 to 22,211 veh/day. Traffic compositions at all sites were dominated by the light vehicles.

Table 3 Summary of traffic characteristics

Site No.	Site 1	Site 2	Site 3	Site 4	Site 5
Total vehicles	22,211	16,824	17,584	10,655	10,290
% LV	97.8	98.5	95.2	94.9	97.0
% HV	2.2	1.5	4.8	5.1	3.0
Min & Max Hourly Traffic Volume (veh/h)	104	160	70	26	16
	1,658	1,264	1,595	852	808
Min & Max Flow Rate (veh/h)	84	120	48	18	4
	1,860	1,388	1,824	980	964
Min & Max Spot Speed (km/h)	10.5	12.2	47.3	11	36.6
	155.5	157.4	128.2	127.9	98.3
Min & Max Space-Mean Speed (km/h)	59.60	68.81	63.94	47.27	56.06
	81.73	94.44	86.61	77.57	84.10

Note: LV – light vehicles including motorcycles & HV – heavy vehicles.

3.2 Variations of Speed–Flow Data

Figure 4 shows the variations of speed–flow data at each of the sites studied. In general, it can be seen that a negative linear form of relationship with a reasonable degree of correlation can be developed for each road segment. This is consistent with the general understanding that speed decreases as traffic volume increases. The intercept, which is normally referred to as the free–flow speed, u_f, is in the range of 60 km/h to 100 km/h. The free–flow speeds were found to be consistent with the speed limits posted for the corresponding road segments.

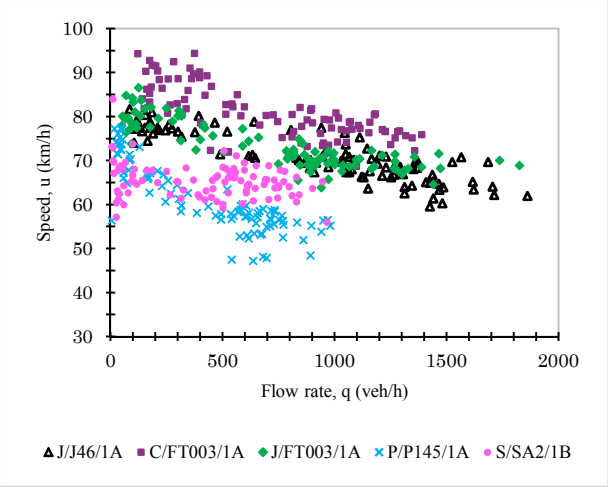

Fig. 4 Speed–flow data at all sites

It is difficult to deduce the actual form of the speed–flow relationship without the data representing the lower region of the plot or the data representing the unstable flow conditions. The current version of USHCM 2010 and MHCM 2011 suggested that a modern–designed two–lane two–way highway can have a capacity up to 1,700 pc/h/direction or up to 3,200 pc/h for both directions of travel. Capacity of each of the road segments considered in this study could not be estimated because the unstable flow conditions did not exist during the period of observations. However, the high flow rate of more than 1,800 veh/h at an average speed of greater than 60 km/h as shown in Figure 4 indicates that the road segments considered in this study have reasonably high practical capacity.

3.3 Comparisons of Speed–Flow Data with USHCM and MHCM

The directional speed–flow data for each of the road segments was compared statistically with the speed–flow data derived using the USHCM 2010 and MHCM 2011 approaches. Figure 5 shows an example of the scatter plots of the speed–flow data for site marked as C/FT003/1A. The speed–flow curves derived from USHCM 2010 and MHCM 2011 are also plotted on the same Figure 5 for visual comparison. Statistical comparisons were based on the analysis of variances, ANOVA, approach.

It can be seen from Figure 5 that under stable flow conditions the USHCM 2010's speed–flow curves and the observed data for road segment marked as C/FT003/1A appear to be consistent in terms of the effect of traffic volume on travel speed. The results of the comparisons with other sites are summarised in Table 4. As indicated, only two of the sites are consistent with the USHCM 2010, i.e. sites C/FT003/1A and J/FT003/1A. It is worth to note that the posted speed limits for these road segments are 70 km/h and 90 km/h, respectively.

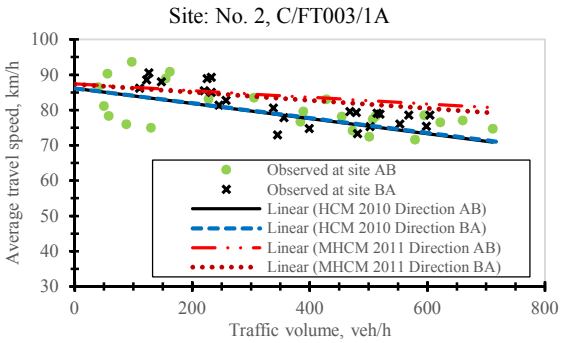

Fig. 5 Comparisons with USHCM and MHCM

The MHCM 2011, on the other hand, produces speed–flow relationships which indicates a much lower effect of flow on travel speed when compared with the speed–flow data obtained from all sites. As a result, the travel speeds estimated by the MHCM 2011 are significantly higher than the observed values as can be seen in Figure 5. And, as indicated in Table 4, speed–flow data at all sites are significantly different from the data predicted using the MHCM 2011 approach. It is worth to note that, for a given traffic volume, the average travel speed estimated by the MHCM 2011 approach is based on the base free flow

speed of 90 km/h and the effect of opposing traffic is not explicitly considered. These might be the possible factors that lead to significant differences occur when compared with the observed data collected for road segments with a posted speed limit of 90 km/h or lower. The USHCM 2010, on the hand, considers both the posted speed limit and the opposing traffic in the analysis.

Table 4 Similarity of speed–flow data with MHCM 2011 and USHCM 2010

Site no.	Site ID	MHCM 2011	USHCM2010
1.	J/J46/1A	No	No
2.	C/FT003/1A	No	*Yes*
3.	J/FT003/1A	No	*Yes*
4.	P/P145/1A	No	No
5.	S/SA2/1B	No	No

4. CONCLUSION

This paper highlights the variations of speed–flow data for selected segments of two–lane two–way highways for a range of traffic flow conditions. The findings of the analysis can be summarized as follows:

- The traditional shape of the speed–flow relationship is difficult to be established because flow breakdowns seldom occur under uninterrupted flow conditions;
- Within the limitation of the samples, the analysis indicates that the USHCM 2010 might be applicable for the analysis of Malaysian road performance under a situation where the posted speed limit is 70 km/h or higher and high geometry standards; and
- Applicability of MHCM 2011 needs further evaluation because it should consider explicitly the effects of opposing traffic flow and the base free flow speed lower than 90 km/h.

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Othman Che Puan obtained his B. Eng. Civil (Hons.) in 1987 from Middlesex Polytechnic (University), UK; Master of Philosophy in Civil Engineering (Highway & Traffic Engineering) in 1991 & PhD (Civil Engineering) in 1999 from University of Wales, Cardiff, UK. He is currently a professor in transportation engineering & planning at Faculty of Civil Engineering, Universiti Teknologi Malaysia. Prof. Dr. Othman Che Puan is a member of graduate engineer of Malaysian Board of Engineer, Malaysian Society for Engineering & Technology (MySET), Transportation Science Society of Malaysia (TSSM) and American Institute of Transportation Engineers (ITE).

Nur Syahriza Muhamad Nor received the B.Eng. (2005) and M.Eng. (2006) in Civil Engineering (Highway & Transportation Engineering) degrees from Universiti Teknologi Malaysia. Currently she is studying for her PhD in Traffic Engineering at Universiti Teknologi Malaysia. She is a Civil Engineer in Public Work Department, Malaysia. Her current interests include Traffic and Transportation Engineering.

Nordiana Mashros received the B.E. (2005), M.E. (2007) in Civil Engineering (Transportation and Highway) and PhD (2013) in Civil Engineering (Traffic Engineering) degrees from Universiti Teknologi Malaysia. She is a Senior Lecturer in Department of Geotechnical and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia. Her current interests include traffic and transportation engineering, transport safety.