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AN ALTERNATIVE METHOD OF ESTIMATING SPACE-MEAN SPEED

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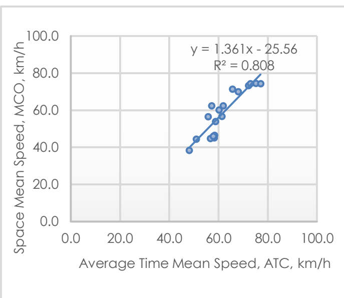
Graphical abstract



Abstract

Average travelling speed usually applied in the traffic analysis as required in the fundamental traffic model. As one type of speed under the space-mean speed, most of the researchers have derived the equation to estimate the space-mean speed. There are a few factors that influence the speed changes along the segment. The fluctuate speed along the segment give an idea to average the spot mean speed from at least two points in order to estimate the space-mean speed. This paper explores an alternative method on how to convert the time-mean speed to space-mean speed that can represent the actual operating speed along segment using the average technique. A total of 18 data sets of time-mean speed and space-mean speed in six segments of uninterrupted two-lane single carriageway road were collected using automatic traffic counter and moving car observer, respectively. Two sets of automatic traffic counter were installed along the segment to record the spot speed and then converted to the time-mean speed, while the moving car observer were conducted concurrently to get the space-mean speed. The data sets were analysed using linear regression analysis. The results of summary of model show a strong relationship with coefficient of determination, R^2=0.808, while ANOVA test results show the coefficient of constant and time-mean speed is not zero with p-value is less than 0.05 at confident level of 95%. The error obtained from this alternative equation are lesser than the established equation and it recommends that the alternative equation is acceptable.

Keywords: Space-mean speed, time-mean speed, two-lane single carriageway road, average technique

1.0 INTRODUCTION

Speed is a fundamental parameter that is used as a measure of road performance. The road performance measures are importance indicators to agency's planning and decision-making especially for providing a better road system. The decision usually involves millions of ringgit in order to provide comfortability for the road user. Therefore, the accurate analysis should be conducted to give the right indicator to the decision maker.

Level of service (LOS) is a qualitative measure used to relate the quality of traffic service. It is used to analyse highways by categorizing traffic flow and assigning quality levels of traffic based on performance measure like speed. The LOS criteria given in the Highway Capacity Manual 2000 (HCM 2000) [1] is based on the United States (US) highway and traffic conditions. In Malaysia, the similar concept of LOS is applied in the Malaysian Highway Capacity Manual 2011 (MHCM 2011) [2], however it is based on the local highway and traffic conditions. For two-lane single carriageway road, the LOS criteria are based on two parameters: percent time-spent-following (PTSF) and average travel speed (ATS) as shown in Table 1 and Figure 1, respectively. The LOS concept places various traffic flow conditions into five levels of service using letters A through E, with A being the best and E being the worst. Even though HCM 2000 [1] uses PTSF as the primary LOS measure for two-lane highways, but ATS is also important for a performance measure as it relates well to road user perceptions of the quality of traffic flow. Thus, assessment and analysis of speed must be carefully conducted to ensure the correct selection of LOS.

Table 1 LOS criteria based on PTSF and ATS [2]

LOS	PTSF (%)	ATS (km/h)
A	≤35	≥70
B	≤50	≥60
C	≤65	≥50
D	≤80	≥40
E	>80	≥30

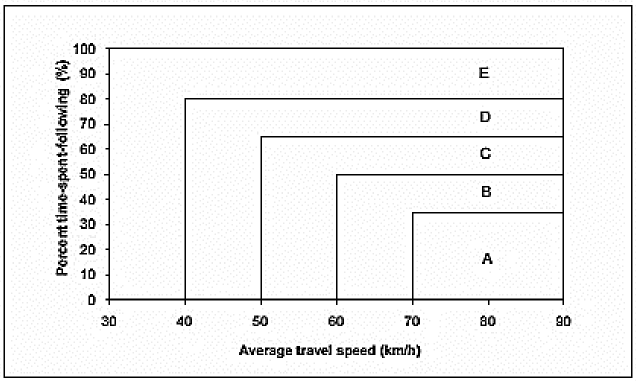


Figure 1 LOS criteria for two-lane highway [2]

In general, speed as described by Khisty and Lall [3] is a rate motion of a vehicle, as distance per unit time, generally in kilometre per hour (km/h). The average travel speed in a traffic stream usually being used due to a broad distribution of individual speed. When the travel time for each vehicle, t_1, t_2, t_3, …., t_n, were observed for n vehicles traversing a segment of length L, thus the average speed can be determined using Equation 1:

$$\acute{\upsilon}_s = \frac{nL}{\sum_{i=1}^{n} t_i} \quad (1)$$

where

$\acute{\upsilon}_s$ = average travel speed or space-mean speed, km/h
L = length of the segment, km
t_i = travel time of the i^{th} vehicle to traverse the segment, hours
n = number of travel time observed

The average travel speed, $\acute{\upsilon}_s$ is also referred as space-mean speed. The 'space' term used to describe the average travel time according to the length of time each vehicle spends in 'space'. On the other hand, the average travel speed can be estimated using the average spot speed or time-mean speed, $\acute{\upsilon}_t$. The time-mean speed is an arithmetic mean of the measured speed of all vehicles passing at a stationary point or fixed roadside point during given time as given in Equation 2:

$$\acute{\upsilon}_t = \frac{1}{n} \sum_{i=1}^{n} \acute{\upsilon}_i \quad (2)$$

where $\acute{\upsilon}_i$ is the spot speed, km/h while *n* represent the number of vehicles observed. Previous studies have shown that space-mean speed and time-mean speed are related. For example, Wardrop [4] derived the first and most well-known relationship between space-mean speed and time-mean speed using similar theory by Khisty and Lall [3] above. He allows the estimation of time-mean speed from space-mean speed and Wardrop's relationship is expressed as Equation 3 [4]:

$$\acute{\upsilon}_t = \acute{\upsilon}_s + \frac{{\sigma_s}^2}{\acute{\upsilon}_s} \quad (3)$$

where σ^2_S is the variance of space-mean speeds. While, Garber and Hoel [5] describe a more direct relationship between space-mean speed and time-mean speed as Equation 4:

$$\acute{\upsilon}_t = 0.966\acute{\upsilon}_s + 3.541 \quad (4)$$

where both space-mean speed and time-mean speed is in km/h unit. As time-mean speed is easier to observe at site as compared to space-mean speed, the Equation 4 was manipulated to perform space-mean speed to the function of time-mean speed, and it can be represent as Equation 5:

$$\acute{\upsilon}_s = 1.035\acute{\upsilon}_t - 3.666 \quad (5)$$

In HCM 2000 [1], it has been stated that a typical relationship between space-mean speed and time-mean speed is as studied by Drake, *et al.* [6] presented in Equation 6. It is expressed that the time-mean speed is normally higher than the space-mean speed.

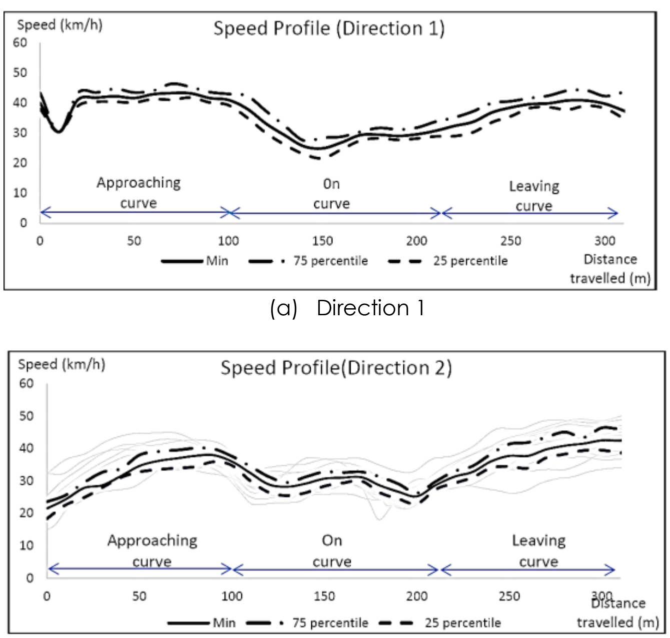
$$\acute{\upsilon}_s = 1.026\acute{\upsilon}_t - 3.042 \quad (6)$$

Currently, Malaysian are using the equation derived by Leong and Awang [7] to produce the space-mean speed using time-mean speed. The established equation was applied in MHCM 2011 [2]. The equation was developed using 82 data set of time-mean speed recorded in the middle of the 3.5 km segment. The time-mean speed data collected were assumed the best data that suit the speed along the segment. The equation was produced as per Equation 7:

$$\acute{\upsilon}_s = 1.016\acute{\upsilon}_t - 1.704 \quad (7)$$

Equation 7 generates a strong relationship between space-mean speed and time-mean speed with the coefficient of determination, R^2 of 0.881. By replacing time-mean speed as 50 km/h for all above equations, the space-mean speed resulted in a lower value than time-mean speed at about 0.9 km/h to 1.9 km/h which is Equation 7 by Leong and Awang [7] give the lowest different between space-mean speed and time-mean speed.

All above equation were established with the assumption that single point data of average spot speed can represent the best value of speed to produce space-mean speed for the whole uninterrupted segment. The uninterrupted segment is defined as a roadway that has no fixed causes of delay or interruption external to the traffic stream [8]. No major junction within the selected length of normal segment is the important criteria that caused to the delay. The criterion of uninterrupted segment is focused on the facilities of the road but not the road alignment or terrain. There are several studies have been conducted and focused on these parameters to identify the speed pattern. Filippo and Marinella [9] explore the road alignment factor that affect the speed along 6.2 km length segment with various geometry and find that there is a lot of elements affect the operating speed at 85th percentile of speed distribution. 69% of the factor were explained by the model i.e. radius, slope and length of the segment. They suggested to conduct further study in order to identify the other factor. Besides that, Munzila *et al.*, [10] studied the effect of speed when entering the curve segment and conclude one of the possible factor that affect the speed changes is the road alignment. On the other hand, the study found that there is fluctuate speed occurred along the curve segment (approaching curve, on horizontal curve and leaving curve). Figure 2 shows the speed pattern in the study for every metre segment. It can be seen that the drop of speed occurred about 10 km/h to 15 km/h. Although the study was conducted at the uninterrupted segment, the pattern does not show where is the best point to get the time-mean speed that can represent the best average travel speed, $\acute{\upsilon}_s$.



(b) Direction 2

Figure 2 Speed profile data observed on curve segment [10]

Noted that the fundamental equation of traffic flow is involving three basic parameters i.e. flow, q (veh/h), density, k (veh/km) and speed, $\acute{\upsilon}_s$ (km/h) where the speed is always the space-mean speed or average speed [3, 5]. The accurate space-mean speed should be applied to get a reliable flow or density to be used for other analysis or applications. Therefore, assumption using the time-mean speed at one point in a segment can lead to produce different estimated space-mean speed due to road geometry factor and indirectly it will affect the accuracy of the value during the applications afterword. Hence, this study try to explore the use of averaged two point time-mean speed data instead of one point as an alternative method on generating estimated space-mean speed.

2.0 METHODOLOGY

2.1 Site Selection

A total of 18 datasets for six segments of two-lane single carriageway from three sites were collected for this study as shown in Table 2.

Table 2 Site description

Site No.	Site ID (State/Road Number/Segment /Direction)	Date	Time
1	J/J4/01/AB Gelang Patah, Johor	8/5/2014	10:00 - 11:00
2		8/5/2014	13:00 - 14:00
3		8/5/2014	16:00 - 17:00
4	J/J4/01/BA Gelang Patah, Johor	8/5/2014	10:00 - 11:00
5		8/5/2014	13:00 - 14:00
6		8/5/2014	16:00 - 17:00
7	J/J46/01/AB Ulu Choh, Johor	18/12/2014	12:00 - 13:00
8		20/12/2014	16:00 - 17:00
9		22/12/2014	12:00 - 13:00
10	J/J46/01/BA Ulu Choh, Johor	18/12/2014	12:00 - 13:00
11		20/12/2014	16:00 - 17:00
12		22/12/2014	12:00 - 13:00
13	A/FT060/01/AB Manjung, Perak	24/12/2014	10:00 - 11:00
14		27/12/2014	08:00 - 09:00
15		27/12/2014	18:00 - 19:00
16	A/FT060/01/BA Manjung, Perak	24/12/2014	10:00 - 11:00
17		27/12/2014	08:00 - 09:00
18		27/12/2014	18:00 - 19:00

The selected segment has uninterrupted flow and located on the Federal or State Road. In order to ensure that there is no interruption on the speed behaviour and the selected speed is in stable condition, the selection of survey sites should meet a few criteria [11]:

i. Homogeneity: Segments is relatively homogeneous in geometric characteristics throughout their whole length.

ii. Junctions: There is no major junction within the segment or within at least 250 m of its endpoints.
iii. Speed limits: No segment contain within it, or within 250 m of its endpoints, any restriction other than the national speed limit.
iv. No. of lanes: No sections of three lane road were permitted within a segment.
v. Road works: There is no road works were taking place along the segment.
vi. Length: Segments should preferably be more than 2 km and not greater than 5 km in length.

2.2 Data Collection Method

Figure 3 shows the typical layout of selected segment, which is in between 2 km to 5 km with at least 1 km distance from junction. On this segment, 24 hours traffic data were collected using two (Automatic Traffic Counters (ATC), which installed at selected point i.e. A and B continuously between 1 to 5 days. Various types of data were obtained including the spot speed of individual vehicles. These data were used to determine the time-mean speed using the Equation 2 as discussed in section 1.0. During the installation of ATC, moving car observer (MCO) method was also conducted during daylight at selected time as shown in Table 2. The method involves the test vehicle and at least three observers. In this technique, the driver of the test car drives into the traffic stream and make a round trip on a test section as shown in Figure 3. Assuming that, the test car drives from starting to the ending segment repetitively. This study has chosen five tests run in each traffic direction. Performing few test runs per traffic direction was required for consistent and unbiased estimates of measured variables [12]. The data collected are the time taken to travel along the segment, the number of vehicles traveling in the opposite lane, the number of vehicles that overtake the test car while it is traveling in the segment and the number of vehicles that the test car passes while it is traveling in the segment. Consequently, the speed of the test vehicle is considered as the average speed or travelling speed, $\acute{\upsilon}_s$ of all vehicles in the traffic stream. This method was used to obtain the space-mean speed. Therefore, the hourly flow rates for AB and BA directions were determined using Equation 8 and Equation 9, respectively:

$$q_{ab} = \frac{(N_b + O_a - P_a)\,60}{T_b + T_a} \quad (8)$$

$$q_{ba} = \frac{(N_a + O_b - P_b)\,60}{T_b + T_a} \quad (9)$$

where,
T = Time taken to travel along the segment, minutes
N = Number of vehicles traveling in the opposite lane, veh
O = Number of vehicles that overtake the test car while it is traveling in the segment, veh
P = Number of vehicles that the test car passes while it is traveling in the segment, veh

Then, average time travel, $\check{T}$ is obtained from the Equation 10 and Equation 11 as follows:

$$\check{T}_{ab} = T_a - \frac{60\,(O_a - P_a)}{q_{ab}} \quad (10)$$

$$\check{T}_{ba} = T_b - \frac{60\,(O_b - P_b)}{q_{ba}} \quad (11)$$

Space-mean speed, $\acute{\upsilon}_s$ is obtained from the Equation 12 and Equation 13 as follows:

$$\acute{\upsilon}_{sab} = \frac{nL}{\sum_{i=1}^{n} t_i} = \frac{L}{\check{T}_a} \quad (12)$$

$$\acute{\upsilon}_{sba} = \frac{nL}{\sum_{i=1}^{n} t_i} = \frac{L}{\check{T}_b} \quad (13)$$

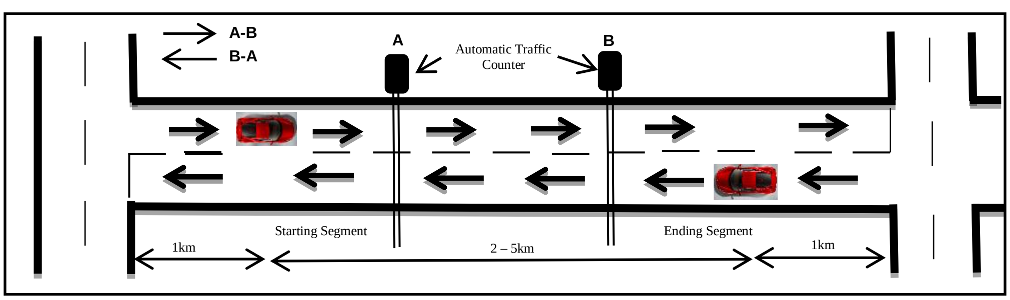


Figure 3 Setup of survey site

2.3 Analysis Method

The 18 datasets of time-mean speed collected using ATC and space-mean collected using MCO were regressed using linear regression analysis. The new model or alternative equation obtained from the analysis was then tested using statistical analysis to check the significance of the model. Subsequently, the estimated space-mean speed was calculated using Equation 7 and alternative equation. The results were then been compared by plotting each of estimated space-mean speed in 45° diagonal line with actual space-mean speed, MCO. The different of each space-mean speed were calculated using the average absolute percent error (APE) [13] as Equation 14:

$$APE(\%) = (\text{Estimated } \dot{\upsilon}_s - \text{Actual } \dot{\upsilon}_s | x100)/\text{Actual } \dot{\upsilon}_s \quad (14)$$

Both error from estimated space-mean speed using established Equation 7 and alternative equation were then compared. The lesser the error represent the accurate estimation of space-mean speed.

3.0 EMPIRICAL RESULTS AND DISCUSSION

Table 3 shows the summary of the time-mean speed collected using ATC and the space-mean speed obtained using MCO data. From this table, it can be seen that time-mean speed were determined for points A and B for each selected segments. The values from both points were then averaged and regressed to space-mean speed collected using MCO to develop the alternative equation, which is based on linear regression.

Table 3 Time-mean speed, ATC and space-mean speed, MCO data

Site No.	Time-mean speed, ATC, km/h			Space-mean speed, MCO, km/h
	Point A	Point B	Average	
1	56.1	60.3	58.2	45.2
2	55.6	61.1	58.3	46.7
3	49.2	52.7	51.0	44.6
4	56.0	57.2	56.6	44.9
5	57.0	58.6	57.8	46.1
6	47.5	48.4	48.0	38.5
7	72.3	51.3	61.8	62.5
8	65.1	49.2	57.1	62.6
9	72.2	50.5	61.4	56.9
10	64.3	53.3	58.8	54.1
11	59.9	51.4	55.7	56.6
12	65.8	54.4	60.1	60.2
13	66.4	64.9	65.6	71.6
14	72.3	71.9	72.1	73.5
15	69.2	66.6	67.9	70.1
16	75.5	74.7	75.1	74.7
17	76.3	77.9	77.1	74.4
18	71.6	74.2	72.9	74.4

From the linear regression developed using the data sets in Table 3, it can be seen in Table 4 that the model has strong correlation with coefficient, R is 0.899. While the coefficient of determination of R^2 is 0.808, which indicates that 80.8% of the variability in space-mean speed is explained by the time-mean speed [14].

Table 4 Model summary of space-mean speed from average time-mean speed

Correlation coefficient, R	Coefficient of determination, R^2	Adjusted R^2	Std. Error of the Estimate
0.899	0.808	0.796	5.59462

The ANOVA test was conducted to observe the significant of the model coefficient, β. The *F* value provides a statistic for testing the hypothesis that β is equal to zero. *F* is the ratio of Mean Square Regression (MSM) and Mean Square Residual (MSE). When the MSM is large relative to the MSE, then the ratio is large and there is evidence against the null hypothesis. Table 5 show The *F* statistic is equal to 2106.54/31.30 = 67.30. The distribution is $F(1, 16)$, and the probability of observing a value greater than or equal to 67.302 is less than 0.05 at 95% confident level. There is strong evidence that β is not equal to zero.

Table 5 Results of ANOVA test

Model	Sum of Square	df	Mean Square	*F*	*Sig.*
Regression	2106.54	1	2106.54	67.30	.000
Residual	500.79	16	31.30		
Total	2607.34	17			

Table 6 presents the coefficient results for the model. The coefficients for both constant and time-mean speed are -25.558 and 1.361 respectively where it is significant with p-value less than 0.05 at 95% confident level.

Table 6 Coefficient results obtained for the model

Variables	Coefficients		*t*	*Sig.*
	β	Std. Error		
Constant	-25.558	10.362	-2.467	.025
TMS(ave), vt	1.361	0.166	8.204	.000

Therefore, the alternative equation to generate the space-mean speed derived by this model is as follows:

$$\dot{\upsilon}_s = 1.361\dot{\upsilon}_t - 25.56 \qquad (R^2 = 0.808) \qquad (15)$$

Figure 4 illustrates the trend line of relationship between space-mean speed and time-mean speed for two-lane single carriageway from this study.

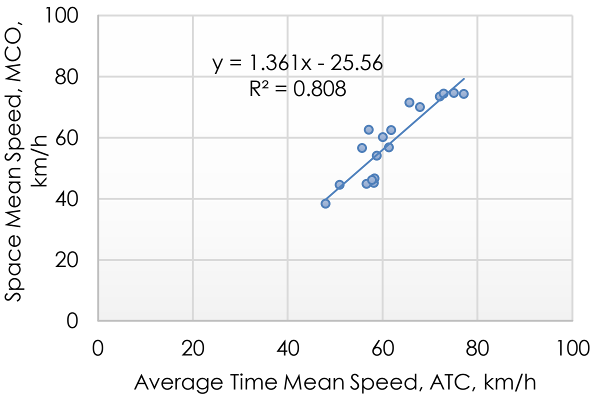


Figure 4 Relationship between space-mean speed and time-mean speed

The normal probability plot of observed and expected cumulative probability data in Figure 5 shows the data scattered in line with 45° diagonal line which show the distribution is equal, hence, the normality distribution is satisfy.

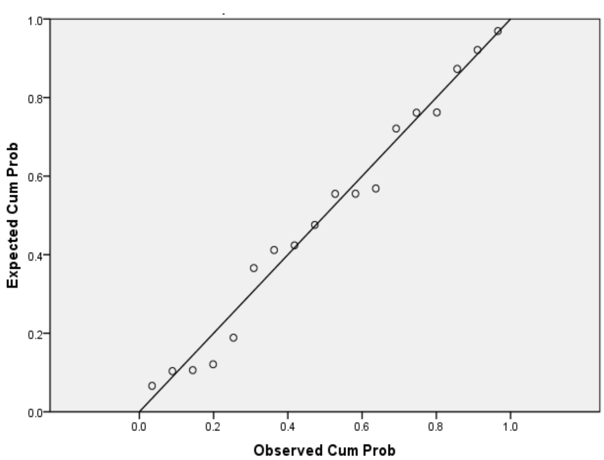


Figure 5 Normal probability plot

The regression standardized residual plot in Figure 6 seems to be randomly scattered around the horizontal axis. Therefore the relationship is accepted.

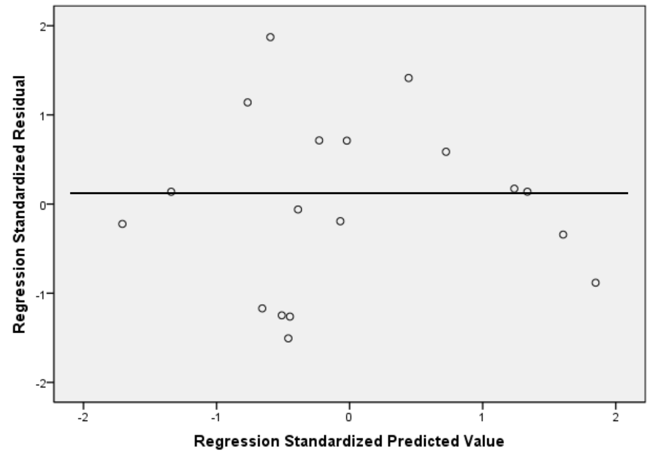


Figure 6 Residual plot

For the validation purposes, both time-mean speed from points A and B for each segment were converted to space-mean speed using Equation 7 as applied in MHCM 2011 [2] and the results of the estimated space-mean speed are shown in Table 7. In the same table, the space-mean speed was also estimated using Equation 14 (alternative equation). The estimated space-mean speeds at both points using equation in MHCM 2011 [2] were then compared with the estimated space-mean speed using alternative equation.

Table 7 Estimated space-mean speeds (ESMS)

Site No.	ESMS, MHCM, Point A, km/h	ESMS, MHCM, Point B, km/h	ESMS, alternative equation, km/h
1	55.3	59.6	53.7
2	54.7	60.4	53.8
3	48.3	51.9	43.8
4	55.2	56.5	51.5
5	56.2	57.8	53.1
6	46.6	47.5	39.7
7	71.8	50.4	58.6
8	64.4	48.2	52.2
9	71.7	49.6	58.0
10	63.6	52.4	54.4
11	59.2	50.5	50.2
12	65.1	53.6	56.2
13	65.7	64.3	63.8
14	71.7	71.4	72.6
15	68.6	65.9	66.9
16	75.0	74.2	76.6
17	75.9	77.4	79.4
18	71.0	73.7	73.7

The estimated space-mean speed above was illustrated in Figure 7. All groups of estimated space-mean speed were scattered around 45° diagonal line. From the observation, it can be seen that the estimated space-mean speed using alternative equation fall closer to 45° diagonal line as compared to others estimated space-mean speed.

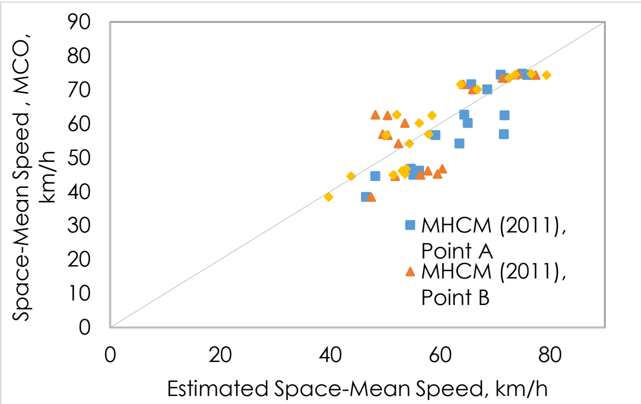


Figure 7 Relationship of space-mean speed and estimated space-mean speed

The results of APE calculated using Equation 15 for each space-mean speed are summarised in Table 8. From this result, it shows that the alternative equation produces lesser error compared to the established model applied in MHCM 2011. Therefore, the alternative equation is acceptable to use as an alternative method to estimate space-mean speed. The average of APE, 7.7% resulted that the new equation can be applied to leverage the error.

Table 8 The average absolute error for each model compared to actual

Model	MHCM (2011), Point A	MHCM (2011), Point B	Alternative equation, Average point
APE, %	11.5	14.3	7.7

4.0 CONCLUSION

From above analysis and discussion, it can be concluded that average spot speed data from both points in a segment can demonstrate space-mean speed for the segment which also known as average traveling speed. Further research with broad of site would be necessary to prove the finding. However, the method is capable of estimating the space-mean speed for two-lane single carriageway.

Although such precision would not be essential in some practical traffic engineering applications where estimation of speed would sufficient, but in other applications, an accurate space-mean speed estimation makes a big difference. For example, traffic modelling and simulation, travel time estimations from spot-speed measurements, intelligent transportation system as an input for the current situation information. All the analyses are highly sensitive to the speed.

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