Measurement of percent time spent following on two-lane highways: an exploration of spot and space-based methodologies

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Abstract. Percent Time Spent Following (PTSF) is used as a key performance measure for two-lane highways as recommended by the HCM2010. PTSF is the average percent of total travel time that vehicles must travel in platoons behind slower vehicles due to inability to pass. Despite its acceptance as performance indicator, PTSF is difficult to measure directly in the field. It is therefore estimated using a surrogate measure based on the spot percent of vehicles travelling with headways less than three seconds (3 s) at a fixed point. However, the application of the 3 s headways as the sole criterion in the surrogate measure is still contentious. On the basis of definition, PTSF is both spatial and temporal variable whereas its estimation is based on fixed point. It is therefore desirable to develop a spatial measurement approach for PTSF that takes into consideration of travel time. A new method was therefore developed for spatial measurement of PTSF using a test vehicle equipped with a GPS-based speed acquisition and video recording system. This study explores the spot and spatial measurement techniques of PTSF. The indicator was then measured using the two approaches concurrently. Data for the study were sampled from 18 directional segments of two-lane two-way highways in Johor and Pahang States, Malaysia. Subsequently, the estimates from these approaches were compared. On comparing the PTSF values from the spot and space-based approaches, it was discovered the latter approach produced lower values than the former in most instances. A statistical test of difference of means at 95% confidence level indicated that the estimates from the two techniques do not differ significantly. This implies that PTSF from spot measurement do not differ much from those based spatial approach developed in this study. Finding from this effort would at least substantiate the application of the spot-based PTSF measuring technique; an issue that has been debatable. It also serves as a response to the contentious issue, which has not received the desired attention from experts previously.

1. Introduction

The Highway Capacity Manuals; HCM2000 [1] and HCM2010 [2] recommended the use of Percent Time Spent Following (PTSF) as a primary service measure for performance assessment and designation of Level of Service (LOS) for two-lane highways. PTSF is a representation of the freedom of motorists to manoeuvre and the ease as well as the convenience of travel within a traffic stream. It is referred to as the average percentage of total travel time that vehicles must travel in platoons behind slower vehicles due to the inability to overtake on two-lane highways [1, 2]. In addition to PTSF, other indicators are used for performance assessment of the subject road class. However, PTSF is regarded
as the main service indicator [2, 4]. Further, PTSF has been the most debatable indicator; not because of its inadequacy as service measure but due to the difficulty associated with its field measurement and the ambiguity associated with the recommended field measurement methodology [5, 6]. On the basis of difficulty associated with field measurement of PTSF, it was recommended that the indicator be estimated using a surrogate measure approach; as the spot proportion of vehicles travelling at headways shorter than three seconds (3 s) [1, 2] or using models derived from such estimates. This approach seems to suggest that the percent of vehicles passing a specific spot on road segment with headways less than 3 s out of the number of observed vehicles over specified time period is a representative of the average proportion of travel time spent in following or platoons over a long section. This assumption has clearly portrayed a clear mismatch between the definition of PTSF and the recommended procedure for its estimation. The recommended procedure does not in any way takes travel time into account in the estimation process. By dissociating the travel time component from the estimation, the procedure seems deficient. From the point of travel time, it implies that PTSF is a segment related measure and not specific point [7]. Hence, the application of 3 s criterion for estimating PTSF based on specific point observation and regarded as representative of long section could be vague. This ambiguity associated with the application of the surrogate measure coupled with the difficulty relating to its field observation made some researchers [7-11] to proposed other service measures as an alternative to PTSF despite its wide acceptance as an adequate measure of effectiveness for performance evaluation of two-lane highways. This indicates that investigation into the search and development of other methods that could be used to measure PTSF along highway segment has not received the most desired attention. The spot-based PTSF measurement technique has been identified with some shortcomings as reported in various studies [6-9, 12-14] which call for the need to explore on other methods. Specifically, an approach that could measure the variable based on space. Some of the shortcomings of the spot- and the rationale behind the space-based measurement techniques as discussed as follows. The spot measurement method suggests that PTSF is derived solely from temporal inter-vehicular arrival intervals based on spot headways less than 3 s. This recommendation seems ambiguous; as PTSF is estimated independent of the travel time associated with its actual definition, which shows an inherent weakness in the method. Since PTSF is regarded as the proportion of total travel time that vehicles must travel in platoons behind slower moving vehicles due to the inability to pass; its estimation procedure should therefore take into account of its spatial attributes. By estimating PTSF based on proportion of vehicles with headways less than 3 s at a fixed point, the procedure seems to have a fundamental weakness of not been able to reflect the spatial characteristic of the indicator. This has significantly exposes a mismatch between the definition and the estimation approach. Some sources claimed that the spot-based approach is ill-defined as the critical headway can be observed both in free-flow and congested conditions, with attendant implication of overestimating PTSF [6, 9, 15] and might translate into unsatisfactory LOS that could be quite low to warrant for improvement.

Difficulty associated with field estimation of PTSF should not be a convincing reason for not exploring on other possible methods that could be applied to measure PTSF along road segment; especially, to justify expenditures on facility improvement. For the fact that to date; PTSF is still an adequate service measure as documented in HCM2000 [1] and HCM2010 [2]; the leading manuals of traffic engineering, it is therefore, essential to explore on other methodologies that could be used to measure PTSF in the field based on spatial observation. This study attempted to propose a new approach for field measurement of PTSF over a segment of two-lane highway based on 3 s headway criterion. The proposed approach is intended to estimate PTSF based on travel time spent in platoons at headways smaller than 3 s. This could produce PTSF values based on actual time spent following over the section as against the existing practice of spot measurement and deemed as representative of segment estimates [16]. Since PTSF is travel time related measure, the most likely way to estimate it, is for the observation to be made within the traffic stream under evaluation. Therefore, this research used a test vehicle or moving car observer (MCO) method based on floating car technique to estimate
PTSF. This study also explores into the agreement or otherwise of PTSF estimates for the spot and space-based measurement techniques.

2. Methodology
This study was carried out to explore on the measurement of PTSF based on spot and spatial techniques. Data for the work were sampled from eighteen (18) representative directional segments of two-lane rural highways in Johor and Pahang States, Malaysia. In the course of the study, PTSF was measured using both the spot and spatial techniques. The spot-based measurement was carried out using a video recording with the aid of a camcorder. However, the space-based measurement was made based on MCO method using an instrumented test vehicle. Sections 2.1 and 2.2 describe the details of the processes involved for both techniques.

2.1. Spot-Based PTSF measurement
As mentioned earlier, the spot measurement was with the aid of a camcorder. This was performed by selecting a specific point within the road section under evaluation and the camcorder installed for recording of the traffic event during the observation period. The camera was installed in a hidden place from the view of motorists in order not to influence the drivers’ behaviour. It was mounted halfway between the two ends of the demarcated study segment and made to face the road such that it is relatively perpendicular to the road. The recorded traffic information was subsequently played back in a computer to retrieve the relevant data. Figure 1 (a) and (b) show the camcorder being installed by the road side during the record and sample playback view in a computer, respectively.

![Camcorder installation](image1)
![Video playback view](image2)

**Figure 1.** Field observation of Time Headway and Traffic Volume.

During the playback, traffic volume and time headway were the main variables extracted. Both the traffic volume and time headways were extracted using Traffic Analysis System (TAS) software, version 1.0.0.11. The TAS is a video-based traffic data processing system used for extraction of classified traffic volume and spot time headways (based on lap time) from field video recorded data by uploading the video into a computer and playback in the TAS environment. Traffic volume was extracted for each direction based on classified count method by pressing an appropriate predefined key for a particular vehicle’s class from the computer keyboard. The time headways for both traffic directions were extracted using the TAS software based on vehicles arrival times at the reference observation point. A vertical adjustable red guideline incorporated into the TAS system was used as the reference point for the indication of vehicles arrivals. Figure 2 depicts the display of the video record during playback for the extraction of time headways. The display shows a number of icons within the TAS dialogue box used for various commands; included are Start, Stop, Exit, Lap Time, Reset Guidelines, and so on. Also within the dialogue box, as the video progresses, an indication of the number of observed Vehicles, Elapsed Time, and Current Lap Time are respectively displayed.
Figure 2. Extraction of Time Headways using TAS software.

In the course of playback, as soon as the front of the subject vehicle coincides with the reference line shown in Figure 2, an indication is made using the lap time icon from the software. This was achieved by clicking on the lap time icon from the TAS dialog box which is alternatively selected using a shortcut key from the computer keyboard. Immediately the indication is made, the system automatically notes and records the lap time of the observed vehicle. This process was repeated for other subsequent vehicles upon their respective arrivals at the reference point over the entire span of observation period determined by the length of the field recorded video. At the end of the video, the process resulted in several number of lap times (corresponding to the vehicles arrival times) from which time intervals between any pair of consecutive lap times give the time headways between pairs of successive vehicles in the traffic stream. Immediately the video playback is completed, the TAS software automatically displays a summary of the recorded lap times and their corresponding time intervals (representing the time headways) for all the observations made as shown in Figure 3.

The displayed summary of lap times and time headways was subsequently saved by exporting it as Microsoft Excel file to a specified location for further processing. On exporting the summary to the location of interest, the retrieved time headways were sorted into two categories. The first category being for all vehicles with headways shorter than 3 s while the second one for vehicles with headways of 3 s or longer. The proportion of the recorded time headways shorter than 3 s out of the total number observed; expressed as percentage was considered as the PTSF over the observation period. Section 2.2 presents space-based PTSF measurement technique.
2.2. Space-Based PTSF measurement

Data for this part of the study were collected using an MCO method. The choice of the MCO method is based on the fact that PTSF is both space and travel time related variable; as such for it to be measured along road segment, the observation has to be made within the traffic stream under study. The observation was conducted in accordance with procedures in the Manual of Transportation Engineering Studies [17] based on floating-car driving technique. In this technique, the driver of the test car drives into the traffic stream under evaluation and overtakes as many vehicles as overtake the test car along the road section as passing opportunities permit. It was affirmed that a test vehicle driven within a traffic stream based on floating car driving technique approximates the behaviour of an average vehicle in the stream, estimates mean travel time, and is usually applied solely on two-lane highways [18-20]. On the basis of this assertion, the time spent in following by the test vehicle over the segment under evaluation is regarded as the PTSF.

In the course of this study, a uniform segment length of 3.50 km was used for the data collection on all the study sites. To generate a single data point six test runs were performed in each traffic direction which was established as satisfactory for reliable and unbiased estimates of travel times and traffic volumes [21]. A passenger car was employed as the test vehicle (test car). The test car was equipped with a Video Velocity Box (VBox). A VBox is a powerful on-board data acquisition system used for measuring speed of moving vehicle, acceleration, and lap timing among other things. It comprises of a VBox video recorder, 10Hz GPS data logger with an external antenna, forward facing camera, secure digital memory card (SD card), and a microphone. For the purpose of this work, the VBox system was used for detection and recording the test car’s speed at any point as it traverses the road segment under evaluation, and also record full traffic information within the road with the aid of the camera. The VBox version (RLVBVD10LT) used in this study measures speed of a moving vehicle with an accuracy of ±0.2 km/h [22] and logged the recorded information into an SD card inserted into the system at 10Hz [23].

Prior to the commencement of the data collection, the VBox was positioned at any convenient place inside the test car and being manned by the test car driver’s assistant. The GPS antenna is then mounted on top of the car roof and its plug screwed to the VBox via GPS socket provided on the VBox. Likewise, the camera is securely fixed to the front windscreen of the test car, adjusted to face forward in a horizontal position and then connected to the VBox using the camera cable. The
microphone was also connected to the VBox for recording of any desired audio in the course of the data collection. The system is powered by plugging the VBox power cable into the cigarette lighter supply of the test car. Subsequently, the VBox can be used for the real data collection. On connecting the VBox to the test car, the system detects and records the speed of the car at every moment as it moves along the study section. The camera attached to the system and fixed on the test car’s front windscreen records the traffic event of the road under study. The VBox system automatically saves all recorded information onto the SD card which is subsequently uploaded to a computer and played back to extract the relevant data.

The video records of the traffic events were subsequently played back in a computer to extract the required data. During the playback of the video, speed of the test car at any point along the road segment is displayed on the computer screen. A typical video scene during the playback is shown in Figure 4. Likewise, the travel time for each traffic direction was determined from the video based on the time taken to traverse the study section. Similarly, the test car following times for each test run were estimated from the video display based on the time spent by the test car behind its immediate lead vehicle.

To estimate the time spent in following or PTSF, the 3 s time headway criterion based on space measurement was used to define the test car as either a follower or free-moving. At any particular time, the test car is only considered in following condition if its time headway relative to its immediate lead vehicle is less than 3 s, otherwise, it is free moving or a leader. The following section described how the time headway between the test car and its immediate lead vehicle is determined.

2.2.1. Determination of Time Headway between test car and Lead Vehicle. The time headway between the test car and its immediate lead vehicle while moving in the traffic stream was determined as the ratio of the distance headway (spacing) between the two vehicles and speed of the test car. The travel speed of the test car at any instant is estimated from the video scene in the course of playback. To estimate the spacing between the two vehicles, the camera used for the traffic events recording was calibrated prior to the data collection. The calibration was aimed at deriving a relationship between the actual spacing (between the test car and lead vehicle) and rear width of lead vehicle at varying distance headways.

The calibration process was made out using two vehicles; one as test car and the other as the lead vehicle. Four (4) categories of vehicles were used as the lead vehicles in accordance with the classification in the Malaysian Highway Capacity Manual [24] in order to cover the various categories of vehicles expected to be encountered in the field. The test car equipped with VBox for continuous events recording. The camera was fixed and adjusted such that it was placed as horizontal as possible.
and made to face forward direction for full record of the calibration process. It was mounted at an approximate height of 1.20 m above the ground surface and this position was maintained throughout the calibration process and also for the actual field data collection. The test car was stationed at one point while the lead vehicle positioned ahead of it at an initial spacing of 7.5 m rear to rear; and then varied in the increment of 5 m. All events were recorded into the VBox after which video record was uploaded and played back in computer for data extraction.

During the playback, the displayed rear width of the lead vehicle, \( b \) (mm), was measured for each position and recorded against the actual ground spacing or distance headway, \( h_d \) (m) between the vehicles. From pairs of these recorded variables, calibration models between \( h_d \) and \( b \) were developed for estimating distance headway from video scene display based on the rear width of a particular type of lead vehicle. Thus, a specific model was developed for each of the four classes of vehicles considered in this study. The four classes of vehicles considered are; passenger cars / small vans (Class 1), lorries / large vans (Class 2), large lorries / trailers (Class 3), and buses (Class 4). However, for class 1 type of vehicle, it was discovered that in Malaysia some vehicles in this class are considerably having smaller rear width than those of most common ones in that class. For instance, a typical vehicle in class 1 with considerable smaller rear width than others are Kancil and its like. Hence, class 1 was further sub-classified into classes 1a and 1b; the former being for the normal passenger car and the latter for Kancil and similar size vehicles. This resulted to the derivation of five calibration models.

From the models developed, for any measured value of \( b \) for a particular class of lead vehicle, a corresponding value of \( h_d \) is estimated. The time headway is then estimated as the ratio between \( h_d \) and the speed of the test car, \( V \), corresponding to the measured \( b \). The estimated headway is then checked against 3 s. If it is less than the 3 s, time spent behind the lead vehicle at that headway is recorded and then taken as the following time until either the displayed speed or width of lead vehicle changes. When either of the variables changes, the variations are noted and recorded accordingly. Thus, the time headway, \( h_t \) is determined using Equation 1.

\[
h_t = \frac{h_d}{V}
\]

(1)

Where, \( h_t \) is the time headway (s), \( h_d \) is the distance headway (m), and \( V \) is the speed of the test car (m/s).

2.2.2. Estimation of Space-Based PTSF. As mentioned earlier, time spent in following or PTSF is considered as the travel time spent by the test car behind a lead vehicle at headways less than 3 s. Therefore, the proportion of the test car’s travel time spent in following is determined as the ratio between the travel time spent behind the lead vehicle at headways shorter than 3 s and the total travel time taken to traverse the study section. Hence, on the basis of floating car driving technique, the proportion of the test car’s travel time spent in following; expressed in percentage represents the PTSF for the segment evaluated. This is based on the assertion that estimates of travel time based on floating car technique are considered as approximate mean for the traffic stream evaluated. In a simple relationship, PTSF was estimated using Equation 2.

\[
PTSF = \frac{\sum_{i=1}^{n} t_{fi}}{T} \times 100
\]

(2)

Where, PTSF is the percent time spent following (%), \( t_{fi} \) is the individual test car’s travel times (following time) behind lead vehicle at headways less than 3 s, and \( T \) is the total travel time taken to traverse the study segment.
3. Results and discussion

Findings regarding derivation of calibration models for the determination of distance headway which are key inputs for the determination of time headway as well as PTSF are presented and discussed herein. Likewise, the results of PTSF estimates from both the spot and space-based approaches are presented and discussed accordingly.

3.1. Calibration models for estimation of Distance Headway

As stated earlier, the VBox camera was calibrated to develop representative models for estimation of distance headway between the test car and lead vehicle within a traffic stream. The estimated distance headway was subsequently used for determination of time headway. These were used along with the speed of the test car to estimate PTSF based on space measurement technique. Equations 3 through 7 present the calibrated models for the estimation of distance headway for vehicles classes 1a, 1b, 2, 3, and 4, respectively.

Class 1a:  \[ h_{da} = 237.71b^{-0.920} \]  
Class 1b:  \[ h_{db} = 210.54b^{-0.922} \]  
Class 2:  \[ h_{d2} = 325.30b^{-0.920} \]  
Class 3:  \[ h_{d3} = 365.01b^{-0.920} \]  
Class 4:  \[ h_{d4} = 358.58b^{-0.921} \]  

Where, \( h_{di} \) is the distance headway (m) for \( i \)th class of vehicle and \( b \) is the displayed rear width of lead vehicle (mm) during video playback.

From the results of the calibrated models, there exists a strong correlation between the variables used in developing the relationships as the values of the coefficient of determinations (\( R^2 \)) ranges from 0.9990 to 0.9994 for the five models developed. Furthermore, the values of the test of significant (\( P < 0.05 \)) for all the models from analysis of variance indicate that the predictor (\( b \)) is significantly related to the dependent variable (\( h_{di} \)) as the \( P - \) value is considerably smaller than 0.05. In terms of application for field estimation of distance headway between the test car and any lead vehicle, an appropriate equation was utilized. Thus, for any measured value of lead vehicle’s width (\( b \)) for a particular class of lead vehicle, a corresponding value of distance headway (\( h_{di} \)) is estimated using the appropriate equation corresponding to the subject class of vehicle. The time headway (\( h_t \)) is then estimated as the ratio between \( h_{di} \) and speed of the test car (\( V \)) corresponding to the measured \( b \), as given in Equation 1.

3.2. PTSF estimates from spot and Space-Based measurements

This section presents the results of PTSF estimates derived from the methodologies explored in this study. It is important to note that for the spot-based PTSF was estimated as the specific point percent of vehicles travelling with time headways less than 3 s out of the total number of vehicles observed. While the space-based PTSF was estimated as the travel time spent by the test car behind the lead vehicle(s) at headways shorter than 3 s over the defined segment for the measurement. The estimated PTSF values using the two approaches as derived from the eighteen (18) directional segments are shown in Figure 5.
From the PTSF results based on spot and space measurements shown in Figure 5, it is observed that there is no definite consistent trend exhibited by the estimates. In many instances, PTSF estimates from spot measurement are higher than those from the spatial approach. The many higher PTSF estimates recorded by the spot-based approach could be attributed the assertion that time headways shorter than 3 s can be observed during low volume, free-flow and congested conditions [6, 9, 15]. Thus, if this could have happened, the spot proportion of vehicles travelling at headways less than 3 s would be more and hence the PTSF. However, in few cases (for study sites 8, 17 and 18), the reverse is the case. Likewise, there are situations where the PTSF estimates from the two approaches are relatively the same. This is common with five study sites (3, 5, 7, 9 and 10). Generally, there are far more occasions of higher PTSF records from the spot measured PTSF than in the case of spatial estimates. Explicitly, ten (10) study sites out of the 18 evaluated recorded higher values than those from the space-based PTSF. To illustrate further comparison between the spot and space-based PTSF estimates, a graphical approach was employed as depicted Figure 6. In the Figure, the scattered points denote the relationship between the two sets of data, while the diagonal line is a plot of 1:1 (45°) - line which serves as a guide in making the comparison among the estimates.
The relationship shown in Figure 5 indicates that greater proportion of the data points are distributed below the 45° line. These data points lied in the region corresponding to Spot-based PTSF estimates; which supports the claim made on the higher values produced by the method in relation to the space-based approach. Data points above the 1:1-line are those for which the space-based PTSF estimates are higher than the spot values while those around the line are estimates which are relatively equal from the two approaches. In order to assess whether the difference in PTSF estimates among the approaches is significant or otherwise, a statistical analysis using t-test of difference of means was performed among the two estimates. Result from the analysis revealed a P-value of 0.901 (P > 0.05), which demonstrates that the difference among the PTSF estimates from the two approaches is not statistically significant. This suggests that spot-based PTSF estimates do not differ much from those based space measurement approach.

Despite the fact that PTSF estimates based on space measurement are not significantly different from those spot-based values, the finding is very useful. Previously, studies [4, 5, 9, 11-14, 25-29] out of numerous simply affirmed that due to the spatial attribute of PTSF, the variable is difficult to measure directly in field. However, none of previous works made any effort to explore whether it is feasible to measure the variable spatially or otherwise. Thus, finding from this effort would at least substantiate the application of the spot-based PTSF measuring technique based on HCM 3 s surrogate measure; an issue that has been debatable for a long time and hence, a contribution to the existing literature. Likewise, this serves as a response to the contentious issue, which has not received the desired attention from experts previously. Interestingly, PTSF estimates derived from the space-based technique were found to be significantly sensitive to the influence of the most essential vehicle-following’s variables on two-lane highways. Thus, the proposed approach was able to reasonably capture the impacts of the vehicle-following’s variables influencing PTSF [30], which is significant attribute of a good technique for measurement of service measures.

4. Conclusion
This research presented an exploration into the estimation of PTSF on two-lane highways using spot and spatial measurement techniques based on HCM 3 s time headway criterion. In the course of the investigation, spot-based PTSF was measured in accordance with procedure outlined in HCM2010; as the specific point proportion of vehicles passing the reference point at headways less than 3 s. In the case of the space-based technique, there is no existing procedure to date. Hence, an effort was made in this study for the development of a new method for measuring PTSF based on spatial observation. The new method utilized an instrumented test vehicle based on floating car technique for measuring the PTSF. Having successfully developed the new approach, it was then applied to measure PTSF on representative segments of two-lane highways. In this new approach, PTSF was measured as the average percent of total travel time spent by the test car behind other vehicles at headways less than 3 s. A comparison between PTSF estimates from the spot and space-based approaches revealed that the latter produced lower values than the former in most instances for the data sets used in this study. However, a statistical test of difference of means at 95% confidence level (α = 0.05) indicated that the estimates from the two techniques do not differ significantly. This implies that PTSF estimates from spot measurement do not differ much from those based on spatial approach developed in this study. Despite this, finding from this effort would at least substantiate the application of the spot-based PTSF measuring technique based on HCM 3 s surrogate measure; an issue that has been debatable for a long time. It equally serves as a response to the contentious issue, which has not received the desired attention from experts previously.
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