MODELLING OF PERCENT TIME SPENT FOLLOWING USING SPATIAL MEASUREMENT APPROACH FOR TWO-LANE HIGHWAYS

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To my parent, family, brothers, and sisters.

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ABSTRACT

Percent Time Spent Following (PTSF) is used as a key service measure for two-lane two-way highways, as recommended by the U. S. Highway Capacity Manual (U. S. HCM). 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. Hence, it is estimated using a surrogate measure, i.e. based on the percent of vehicles travelling with headways less than 3 s as recommended by the U. S. HCM or use of a model derived from such estimates or a simulation approach. However, the applicability of the 3 s headways as the sole criterion in the surrogate measure is still debatable. By definition, PTSF is a spatial variable, whereas its estimation is based on fixed point, which may not be a representative of a segment's performance. Therefore, this approach fails to incorporate the travel time associated with PTSF. Hence, it is desirable to develop a spatial measurement approach for PTSF that takes into account of travel time and to derive a new PTSF model. This could substantiate the application of the 3 s surrogate measure. This study explores the application of test vehicle method for spatial estimation of PTSF and derives a model based on traffic flow and roadway geometric variables. Data for the study were sampled from twenty four (24) directional segments of two-lane two-way highways in Johor and Pahang States, Malaysia. A test vehicle equipped with a GPS-based speed acquisition and video recording system was used for the data sampling. PTSF was estimated as the average percent of total travel time spent by the test vehicle behind slower vehicles at headways less than 3 s. An empirical model to estimate PTSF for ranges of traffic flow and roadway geometric conditions with a reasonable accuracy was developed. A statistical analysis showed that there is no significant difference between PTSF obtained from the model derived in this study and those from the surrogate measure at $\alpha = 0.05$. This finding supports the application of the surrogate measure based on the U. S. HCM which had been debated for long. It equally serves as a response to the contentious issue, which had not received the desired attention from experts hitherto. However, a comparison between PTSF from this study model and each of the Malaysian Highway Capacity Manual (MHCM) and the U. S. HCM models revealed that both MHCM and U. S. HCM models overestimate PTSF significantly at $\alpha = 0.05$. This implies that PTSF based on the MHCM and U. S. HCM models would lead to erroneous designation of a road segment's level of service, which would in turn suggest for a premature facility improvement with attendant unjustified expenditures.

ABSTRAK

Peratus Masa Mengekor (PTSF) digunakan sebagai pengukur utama tahap perkhidmatan jalan dua lorong dua hala seperti yang dicadangkan oleh U.S. Highway Capacity Manual (U. S. HCM). PTSF adalah purata peratus jumlah masa perjalanan di mana kenderaan terpaksa bergerak dalam platun di belakang kenderaan yang bergerak perlahan kerana ketiadaan peluang untuk memotong. Walaupun PTSF diterimapakai sebagai pengukur prestasi, namun ia sukar diukur secara langsung di lapangan. Justeru itu, PTSF dianggar menggunakan kaedah gantian yang berdasarkan peratus kenderaan yang bergerak dengan jarak kepala kurang daripada 3 saat seperti dicadangkan oleh U. S. HCM atau menggunakan model yang dibina berdasarkan data jarak kepala 3 saat atau model yang dibina berdasarkan pendekatan simulasi. Walau bagaimanapun, kebolehgunaan jarak kepala 3 saat sebagai satu-satunya kriteria dalam kaedah gantian masih dipertikaikan. PTSF berdasarkan kaedah gantian mungkin tidak menggambarkan prestasi keseluruhan segmen jalan kerana ia diukur pada satu titik tetap di atas jalan sedangkan secara definisinya PTSF adalah pembolehubah ruang. Jadi, kaedah gantian gagal mengambilkira masa perjalanan yang berkaitan dengan PTSF. Maka, adalah wajar untuk membangunkan kaedah pengukuran PTSF berdasarkan ruang yang mengambilkira masa perjalanan dan merumuskan model PTSF yang baharu. Pendekatan ini boleh dijadikan asas untuk menyokong aplikasi kaedah gantian yang berdasarkan kriteria 3 saat. Kajian ini meneroka penggunaan kaedah kenderaan ujian bagi penganggaran PTSF berdasarkan ruang dan menghasilkan model PTSF berdasarkan pembolehubah aliran lalu lintas dan geometri jalan. Data bagi kajian telah diambil di dua puluh empat (24) segmen jalan berdasarkan arah lalu lintas jalan dua lorong dua hala di Negeri Johor dan Pahang, Malaysia. Kenderaan ujian yang dilengkapi dengan perakam kelajuan berasaskan GPS dan sistem rakaman video telah digunakan untuk pensampelan data. PTSF dianggarkan sebagai purata peratus jumlah masa perjalanan yang dialami oleh kenderaan ujian mengekori di belakang kenderaan yang bergerak perlahan pada jarak kepala kurang daripada 3 saat. Model empirikal untuk menganggar PTSF bagi pelbagai aliran lalu lintas dan keadaan geometri jalan dengan kejituan yang munasabah telah dibangunkan. Analisa statistik menunjukkan bahawa perbezaan antara PTSF yang didapatkan dari model kajian ini dan PTSF berdasarkan kaedah gantian adalah tidak ketara pada pada $\alpha = 0.05$. Dapatan ini menyokong penggunaan kaedah gantian seperti yang dicadangkan dalam U. S. HCM yang selama ini dipertikaikan. Ia juga membantu menjawab isu yang dipertikaikan yang sebelum ini tidak diberi perhatian oleh mana-mana pakar. Walau bagaimanapun, perbandingan antara PTSF dari hasil kajian ini dan setiap model yang digunakan dalam Malaysian Highway Capacity Manual (MHCM) dan U. S. HCM mendapati bahawa kedua-dua model MHCM dan U. S. HCM telah terlebih anggar PTSF dengan ketara pada $\alpha = 0.05$. Dapatan ini menunjukkan bahawa PTSF berdasarkan model MHCM dan U. S. HCM akan membawa kepada penetapan paras khidmat segmen jalan yang tidak tepat yang mana akan menyebabkan cadangan penaiktarafan fasiliti jalan dibuat secara pra-matang yang membabitkan penyediaan peruntukan kewangan tanpa asas.

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LIST OF ABBREVIATIONS

ATS	-	Average Travel Speed
ATS/FFS	-	Average Travel Speed as Percent of Free-Flow Speed
ATSpc	-	Average Travel Speed of Passenger Cars
ATSpc/FFSpc	-	Average Travel Speed of Passenger Cars as a Percentage of Free-Flow Speed of Passenger Cars
E	-	East
FD	-	Follower Density
GPS	-	Global Positioning System
HCM	-	Highway Capacity Manual
HV	-	Heavy Vehicles
ID	-	Identification Number
ITE	-	Institute of Transportation Engineers
LOS	-	Level of Service
LV	-	Lead Vehicle
LW	-	Lane Width
MCO	-	Moving Car Observer
MHCM	-	Malaysian Highway Capacity Manual
m : s	-	Minutes : Seconds
MTES	-	Manual of Transprtation Engineering Studies
MVRT	-	Moving Video Recording Technique
N	-	North
NB	-	North Bound
NPZ	-	No-Passing Zones
pc/h	-	Passenger car per Hour
PCE	-	Passenger Car Equivalent
PF	-	Percent Followers
PFFS	-	Percent of Free-Flow Speed

PI	-	Percent Impeded
PTD	-	Percent Time Delay
PTSF	-	Percent Time Spent Following
$PTSF_d$	-	Directional Percent Time Spent Following
SB	-	South Bound
SHW	-	Shoulder Width
SMS	-	Space Mean Speed
TAS	-	Traffic Analysis System
TC	-	Test Car
TRB	-	Transportation Research Board
TWOPAS	-	TWO-lane PASsing
U. S.	-	United States
v/c	-	Volume-to-Capacity Ratio
VBox	-	Velocity Box
veh/h	-	Vehicle per Hour

LIST OF SYMBOLS

a	-	Coefficient for determination of PTSF for directional segments
b	-	Coefficient for determination of PTSF for directional segments
l	-	Length of study segment
h_d	-	Distance heaway or spacing
$h_{d_{1a}}$	-	Distance heaway or spacing for vehicle class 1a
$h_{d_{1b}}$	-	Distance heaway or spacing for vehicle class 1b
h_{d_2}	-	Distance heaway or spacing for vehicle class 2
h_{d_3}	-	Distance heaway or spacing for vehicle class 3
h_{d_4}	-	Distance heaway or spacing for vehicle class 4
h_t	-	Time heaway
$h_{t_{1a}}$	-	Time heaway or spacing for vehicle class 1a
$h_{t_{1b}}$	-	Time heaway or spacing for vehicle class 1b
h_{t_2}	-	Time heaway or spacing for vehicle class 2
h_{t_3}	-	Time heaway or spacing for vehicle class 3
h_{t_4}	-	Time heaway or spacing for vehicle class 3
$f_{np/d}$	-	Adjustment for no-passing zones and directional split on PTSF
f_{np}	-	Adjustment for the effect of percentage of no-passing zones on PTSF
$f_{np,\ PTSF}$	-	Adjustment to PTSF for the effect of percentage of no-passing zones
M_n	-	Number of opposing vehicles met when the test vehicle was travelling north
M_s	-	number of opposing vehicles met when the test vehicle was Travelling south

O_n	-	Number of vehicles overtaking test vehicle when travelling to the north
O_s	-	Number of vehicles overtaking test vehicle when travelling to the south
P_i	-	Probability of a vehicle being impeded and travelling at speed less than the desired speed
P_n	-	Number of vehicles passed by the test vehicle when travelling to the north
P_p	-	Probability of a vehicle being part of a vehicular platoon using Cut-off headway definition of platoon
P_s	-	Number of vehicles passed by the test vehicle when travelling to the south
q_d	-	Flow rate in the analysis direction
q_o	-	Opposing flow rate
q_n	-	Hourly traffic volume for northbound
q_s	-	Hourly traffic volume for southbound
R	-	Coefficient of multiple correlation
R^2	-	Coefficient of determination
$\overline{R}$	-	Difference between maximum and minimum speeds of initial test runs
SMS_n	-	Space-mean speed for northbound traffic
SMS_s	-	Space-mean speed for southbound traffic
t_f	-	Individual test car travel time (following time) behind lead vehicle at headway less than 3 s
t_{fm}	-	Individual test car travel time (free-moving time) behind lead vehicle at headway less than 3 s
T	-	Total travel time taken by test car to traverse study segment
T_n	-	Travel time when test car is travelling north
T_s	-	Travel time when test car is travelling south
T_{nave}	-	Average travel time for all northbound traffic
T_{save}	-	Average travel time for all southbound traffic
v_d	-	Demand flow rate in the analysis direction
v_i	-	Running speed associated with travel run *i*
v_p	-	Two-way Demand Flow Rate

$v_{d,\ PTSF}$	-	Flow rate in the analysis direction for estimation of PTSF
$v_{o,\ PTSF}$	-	Flow rate in the analysis direction for estimation of PTSF
v_{tc}	-	Speed of test car
w	-	Width of lead vehicle

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Provision of highway facilities comprises of various stages including planning, design, and actual construction. For the facility to perform efficiently, careful estimation and forecasting of future traffic demand is required before the actual design commenced which is subsequently followed by the construction. Upon completion of the construction processes, the facility is usually opened to public. Once the facility commenced operation, its performance or quality of service changes with time and thus needs to be monitored to ensure that it can accommodate the traffic demand designed and constructed for. According to the U. S. Highway Capacity Manual; HCM 2010 (TRB, 2010), the quality of service of a highway segment is evaluated based on concept of level of service (LOS). The LOS is a qualitative measure defining the operating conditions within a traffic stream.

The LOS concept has been utilized as a criterion to describe the operating conditions within a traffic stream in terms service measures, which rates highway's performance based on the traffic conditions using six scales of LOS. The different scales of LOS are defined in terms of a letter scheme ranging from A through F; with LOS 'A' denoting the best operating condition where drivers have the choice to move at their desired travel speeds, and LOS 'F' being the worst indicating congested flow condition at which traffic demand exceeds capacity. Depending on the type of highway facility, different service measures are used to describe the operating conditions within the traffic stream.

Owing to the various functions served by two-lane highways, these facilities are categorized into three classes; as I, II and III (TRB, 2010). Class I two-lane highways are those that serve as main arterials, major routes for daily commuters and most often serve long distance trips. On this class of two-lane highways, motorists anticipate to drive at relatively high travel speeds. Class II two-lane highways serve as access to class I roads and functioning as recreational roads. They typically serve short distance trips and motorists do not expect high travel speeds on this class of facility. On the other hand, the class III two-lane highways serve relatively developed areas and could be sections of class I or II passing through small settlements or recreational areas. They are mostly characterized by lower speed limits reflecting the high activity level of developed areas. The operational performances of these three classes of two-lane highways are evaluated based on three measures of effectiveness.

The three measures of service used for assigning the LOS for two-lane highways are; percent time spent following (PTSF), average travel speed (ATS), and percent of free-flow speed (PFFS). PTSF is a representation of the freedom of motorists to manoeuvre and the ease as well as the convenience of travel within the 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 (TRB, 2010). ATS is considered as a reflection of mobility on a highway segment and regarded as the space mean speed of all vehicles within a traffic stream (TRB, 2010). The third service indicator is PFFS which represents the ability of motorists to travel at or close to the highway's posted speed limit. The LOS for class I two-lane highways is assigned based on PTSF and ATS because both delay and travel speed are deemed essential to drivers. On class II two-lane segments, PTSF is the sole service measure as speed is not regarded as significant factor to motorists. For class III segments, PFFS is used as the measure of effectiveness for the performance analysis. It is estimated as the ratio of the mean travel speed and free-flow speed (TRB, 2010).

Among the three service indicators for the different classes of two-lane highways, PTSF has been the most debatable one; not because of its inadequacy as service measure but due to the difficulty related with its field measurement and the ambiguity associated with the recommended field estimation procedure. This is also coupled with its significance in the performance assessment of two-lane highways. PTSF, it is regarded as the primary service measure (Al-Kaisy and Freedman, 2013; TRB, 2010) and sole performance index for classes I and II two-lane highways, respectively. PTSF has been identified and utilized as key measure of effectiveness for two-lane highways by the HCM 2000 (TRB, 2000) and HCM 2010 (TRB, 2010). However, this parameter does not lend itself easy to direct field measurement.

On the ground of difficulty associated with field measurement of PTSF, it was recommended that the variable be estimated based on a surrogate measure approach; as the spot proportion of vehicles travelling at headways shorter than three seconds (3 s) (TRB, 2000; TRB, 2010) or using models derived from such estimates. This approach seems to suggest that the percent of vehicles passing a particular spot of 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 segment. This assumption has clearly portrays a clear mismatch between the definition of the term 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 becomes highly deficient.

From the point of travel time, it implies that PTSF is a segment related measure and not specific point (Romana and Pérez, 2006). 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 (Al-Kaisy and Freedman, 2010; Al-Kaisy and Karjala, 2008; Catbagan and Nakamura, 2006; Hashim and Abdel-Wahed, 2011; Romana and Pérez, 2006) to proposed other service measures as an alternative to PTSF despite its wide acceptance as adequate measure of effectiveness for performance evaluation of two-lane highways. This appears to suggest that investigation into the search and development of other methods that could be used to measure PTSF along highway segment does not receive the most desired attention.

For the fact that to date; PTSF is still an adequate service measure as documented in (TRB, 2000; TRB, 2010), the leading manual of traffic engineering, it is therefore, essential to explore on other approaches that could be used to measure PTSF in the field based on space observation. This study attempts to employ the use of test vehicle through moving car observer (MCO) method based on floating car for field estimation of PTSF over a segment of two-lane highways.

1.2 Problem Statement

Two-lane highways constitute the most common type of highways in many countries. Traffic flow on this type of facilities is different from those on multilane highways, and freeways. On two-lane highways, vehicles travelling on either traffic lane are facing on coming vehicles in the opposing direction and they could be subjected to delay due to inability to overtake slower moving vehicles. It is equally characterized by vehicular interactions within the stream; not only in the same travel lane but also with those in the opposing travel direction. The influence of the interactions usually strengthens with increase in traffic level in the two directions. This situation leads to the formation of platoons; because for fast vehicle to conveniently and safely pass a slow moving one, it inevitably requires the use of the opposing lane, which heavily depends on sufficient sight distance and acceptable gap in the opposing direction.

This phenomenon implies that the operational conditions on two-lane roads are highly associated with interaction among the vehicles in the traffic stream which increases with rise in the number of vehicles. However, on the same travel direction, the interaction between any pair of successive vehicles diminishes when the time headway between them exceeds a value of 6 s (Al-Kaisy and Karjala, 2010; Vogel, 2002) or longer than a threshold headway value that fell in the range of 5 to 7 s (Al-Kaisy and Durbin, 2011). On the other hand, when the level of the interaction is shorter than 3 s, the succeeding vehicle is referred to as a follower or in platoon (TRB, 2000; TRB, 2010). These distinct operational characteristics of two-lane highways made the evaluation of their operational performance rather difficult and compelled experts in traffic engineering to keep on exploring on most appropriate methods to define the quality of traffic flow on them.

The United States Highway Capacity Manuals (TRB, 2000; TRB, 2010) identified and recommended PTSF as a key service indicator for two-lane highways and thus define the LOS. When PTSF was first introduced in HCM 2000 as service measure for two-lane highways; many countries used the procedures described in the manual for operational performance assessment of the subject road class in their locality (Bessa and Setti, 2011). PTSF defined as the average percentage of total travel time that vehicles must spent travelling in platoons behind slower moving vehicles for being unable to pass; is still a widely accepted service measure for two-lane highways. Despite its acceptability, the indicator is difficult to measure directly in the field. For this sole reason, field measurement PTSF has been on the basis of specific point observation along a segment based on surrogate measure; as the percentage of vehicles travelling with headways shorter than 3 s (TRB, 2000; TRB, 2010) or using models developed based on such estimates.

The surrogate measure method suggests that PTSF is derived solely from temporal inter-vehicular arrival intervals based on spot headways less than 3 s. This recommendation by the HCM seems irrational; as PTSF is estimated independent of the travel time associated with its actual definition, which is a significant inherent weakness in the procedure.

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 takes 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. In other words, the procedure fails to incorporate the travel time component associated with variable as explicitly contained in PTSF definition. This has significantly exposes a mismatch between the definition and the estimation approach. More so, in applying the approach, the manual fails to clearly outline guidelines regarding the observation procedure with respect to the selection of appropriate measurement location as well as the length of observation period (Romana and Pérez, 2006). Thus, this weakness and lack of clear guide could lead to errors in measuring PTSF.

Furthermore, the acceptance surrogate measure procedure for measuring PTSF by researchers has been described as an unfortunate decision; as the method is ill-defined, and the critical value can be observed both in free-flow and congested conditions, with attendant implication of overestimating PTSF (Laval, 2006). The critical headway value could even be observed in situations where drivers travel at highway's posted speed limit or higher. In a situation where a following driver travels at posted speed limit behind a lead vehicle (travelling at posted or higher speed) at headway of less than 3 s, this scenario should not be regarded as part of PTSF estimates. This is because; by regulation the following driver is prohibited from overtaking while travelling at posted speed. On this account, estimates of PTSF based on headways shorter than 3 s at specific point could be large even during low traffic condition, and thus translates into unsatisfactory LOS that could be quite low to warrant for improvement or upgrading (Van As and Van Niekerk, 2004). Likewise, the use of the headway less than 3 s approach at specific spot to estimate PTSF could produce similar results for two distinct traffic streams (Al-Kaisy and Durbin, 2008).

One other contentious point is that whether PTSF estimates based on the 3 s headway criterion at specific point really represents the time spent in following over a long section of two-lane highway or not. Even though the spot observation has been the most common and simplest approach for time headway measurement; however, the approach was described as the prime problem associated with headway data collection (Luttinen, 1996). Considering spot PTSF estimates as representatives of road segment values could, perhaps, be true for short sections with relatively homogeneous flow and road conditions. However, on longer sections with different field conditions relating to traffic flow, operational performance, and sight distance (proportion of no-passing zones), PTSF estimates could be different from those in the former condition; as spot estimates might not really capture the effects these features accurately.

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. Previous study (Al-Kaisy and Durbin, 2008) demonstrated that for situations where highway's operational performance varies over a segment, multiple times spent in following could be measured and then summed up to estimate the proportion of following on the highway segment. It is therefore, most desirable to examine the existing practice for field estimation of PTSF based on spot fraction of headways less than 3 s or use of models derived from this procedure. Specifically, to explore on alternative methods that could estimate the indicator over a road segment as against current practice of spot measurement and regarded as representative of long section.

Currently, the operational performance assessment of two-lane highways in Malaysia was adapted from that of the U. S. HCM. The Malaysian Highway Capacity Manual; MHCM 20011 (HPU, 2011) recommends the use of a model developed based HCM 3 s surrogate measure procedure for estimating PTSF. A model developed based on a procedure that assumes time spent following at a point is the same as that over a long section of roadway. The application of the 3 s headway criterion for estimating PTSF is still debatable; because instead of the criterion being applied over space, it is recommended to be observed at specific point.

The main point of contention being raised here is not about questioning the adequacy of the 3 s critical value as surrogate measure for field estimation of PTSF as the cut-off headway has been extensively regarded satisfactory for platooning. However, the procedure used in applying the criterion is highly doubtful. The factual association of PTSF with travel time is the principal motive behind its consideration as a spatial measure. Accordingly, its observation at a fixed point and regarded as representative of long section is questionable. It is therefore, essential to develop alternative procedures that are closer to reality for field estimation of PTSF; particularly, one that would approximate the indicator based on space observation. Hence, PTSF estimates from such approach can be used to develop a model for predicting the measure.

This study attempted to propose a new approach for field measurement of PTSF over a section of two-lane highways based on HCM 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 contrary to the existing practice of spot measurement and considered as representative of segment estimates (Ibrahim et al., 2013b). 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 method based on floating car technique to estimate PTSF.

The choice of the method is on based on the affirmation 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 (Roess et al., 2004). PTSF estimates from this approach combined with the variables influencing it were used to develop a representative empirical PTSF model. Findings from such investigation could serve as the basis to justify the application of the 3 s approach based on specific point observation. More importantly, the findings would be useful in evaluating the implications of using models derived from the surrogate measure approach for estimating PTSF. Furthermore, the findings would equally contribute in advancing the existing practice on performance assessment of two-lane highways.

1.3 Research Objectives

The aim of this study is to develop a percent time spent following (PTSF) model for operational performance evaluation of two-lane highways. To achieve this, the following objectives are set forth:

(i) To develop a new proposed approach for field estimation of PTSF based on space observation using a test vehicle method.

(ii) To estimate PTSF using the new proposed method on various representative segments of two-lane highways.

(iii) To develop an empirical PTSF model for performance assessment of two-lane highways.

1.4 Scope and Limitations

Basically, the scope of this research comprised of two aspects; field data collection and analysis of the data collected. In terms of data collection, PTSF was measured in the field on various segments of two-lane highways based on space observation for the development of representative empirical PTSF model. The study sites used for the data collection were drawn from representative two-lane highways from Johor and Pahang States, Malaysia. They were chosen such that segments with varying ranges of traffic flow conditions and compositions as well as geometric features are utilized. In terms of data analysis, an empirical PTSF model was developed for operational evaluation of two-lane highways and the model was validated using other data sets (collected during different periods, traffic conditions, and compositions) different from the ones used in the modelling. Furthermore, PTSF estimates based on the model developed in this study were compared with those based on HCM 3 s surrogate measure procedure, aimed to ascertain their consistency or otherwise. Similarly, PTSF estimates from this study model were compared with those based on each of MHCM 2011 and HCM 2010 models. This comparison was made with a view to evaluate the implications of using the MHCM and HCM models, which were developed on 3 s surrogate measure and simulation approaches, respectively.

A major limitation of this research is that the space-based PTSF estimation technique proposed in this study and used for development of PTSF model is more suitable for segments on level terrain, with favourable geometriy, characterized by low to medium percentages of no-passing zones (NPZ). Generally, most two-lane highways in Malaysia are located on level terrains (HPU, 2011). Hence, road segments with percentages of NPZ referred to fall within level terrains as reported in the Malaysian Highway Capacity Study Stage 3 (USM, 2011) were used for the data collection in this study. This limitation is necessary; because, on segments with different features from these, the desired accuracy of the constituent variables to be measured (distance and time headways) for estimating PTSF will be difficult to achieve.

1.5 Significance of the Study

This study explored and presented a new methodology for field estimation of PTSF over a section of two-lane highways, estimated PTSF using the new approach, and developed an empirical PTSF model. Findings from this study would provide a basis to substantiate the application of the HCM 3 s surrogate measure approach for estimating PTSF which has been debatable for long and hence, a contribution in that respect. It would equally serve as a response to the contentious matter, which had not receive any attention from experts or explored previously. Likewise, the findings would serve as a means of evaluating the implications of using models derived from the surrogate measure method for estimating PTSF, such as MHCM 2011. They would also be useful in examining the implication of using other models such as that of HCM 2010, which was developed based on simulation approach, and used for estimating PTSF as well.

Since the PTSF model developed in this study was based on empirical data collected under both traffic and roads conditions in Malaysia, it is expected that the model would be useful in contributing to the Malaysian practice relating to the operational performance analysis of two-lane highways. In addition, the findings would assist in decision making regarding facility improvement, especially to justify expenditures associated with the improvement. While the PTSF model developed in the current study could be useful for assessing the operational performance of two-lane highways in Malaysia, the new approach developed in could be applied elsewhere for the development of condition-based PTSF models.

1.6 Thesis Structure

This thesis is organized in eight Chapters with each one describing a particular aspect of the entire research. Chapter 1 describes the background of the study, statement of the problem that motivated the need for this research, objectives of the study, scope and limitations, and significance of the study. Chapter 2 presents a review of relevant existing literatures on operational performance analysis of two-lane highways, service measures used for the performance analysis, with specific emphasis on PTSF. The

Chapter discusses the current issue regarding approaches used in measuring PTSF, their strengths and weaknesses, and suggestions on the way forward in advancing the existing practice. Chapter 3 presents the detailed description of the methodology employed in conducting the research. The fourth Chapter covers the description of the detiled processes used for data collection in the course of the study. Chapter 5 presents and discusses the results obtained from the analysis of the sampled data. Chapter 6 presents the development of percent time spent following (PTSF) model and its validation. This Chapter also presents a comparative analysis among PTSF estimates from this study model and HCM 3 s surrogate measure technique. The seventh Chapter presents the application of the model developed in this study, comparison between PTSF estimates from this study model and other models. In addition, the Chapter presents the implications of the findings from this study, particularly, those associated with applications of this study model and other models for estimation of PTSF. Chapter 8 outlines the fundamental conclusions drawn from this investigation and suggestions for further research.

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