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REVIEW OF PERCENT TIME SPENT FOLLOWING (PTSF) AS PERFORMANCE MEASURE FOR TWO-LANE HIGHWAYS

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ABSTRACT

Percent Time Spent Following (PTSF) is implemented by the Highway Capacity Manual (HCM) as key service measure for evaluating the level of service of two-lane highways. However, to measure PTSF directly in the field is complicated. Because of this complication, estimation of PTSF based on analytical procedure which uses equations derived from simulations and field observations at given location based on surrogate measure; as the percent of vehicles traveling with headway less than 3 seconds (3 s). Findings from existential studies confirmed that analytical procedures used by HCM in evaluating PTSF yield results that are irreconcilable with the 3 s surrogate measure and mostly overcapitalize the indicator. This paper presents a review on the estimation of PTSF on two-lane highways and suggests presumptive approach to affirm the application of the current practice. Further, the authors of this paper argued that the use of 3 s as surrogate for estimating PTSF based on field observation at a specific point may not represent the actual time spent following over a long segment of two-lane highway since PTSF is space related measure. Hence, the authors suggested the use of test vehicle approach and to find out the different approach for heterogeneous traffic condition on highway segment .It is expected that this review and suggestion offered will contribute in advancing performance analysis of two-lane highways.

Keywords: Overcapitalize , Surrogate, Heterogeneous

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I. INTRODUCTION

Flow of traffic on two-lane highways is dissimilar from that on other type of carriageway mainly because vehicles traveling on either lane are facing oncoming traffic in the opposite lane and they may be subject to dawdling because of their incapability to pass slow moving vehicles moving on highway. Two lane highway also characterized by vehicular interactions in the traffic stream; not only in the same direction of travel but also in the opposite one. As the traffic flow in both direction increases, the effect of these interactions generally strengthens. This, in turn, create the formation of platoons as for a fast moving vehicle to safely pass a slow moving one; it needs the use of opposite lane which depends upon sufficient sight distance and permissible gap in the opposing lane of highway.

An analytical method is provided by HCM 1950 for capacity analysis on two-lane highways. The manual gear three different types of capacity: basic, possible and practical, portraying capacity under ideal, prevailing and reasonable driving conditions, respectively. According to HCM 1950 operating speed was performance measure for practical capacity to account for the "quality of service" on two-lane highways because engineers were eager about the traffic situation experienced by road-users; they were not interested in the maximum performance of the system only.

HCM 1965 unrolled the idea of practical capacity to the well-known LOS concept. Six LOSs (A–F) were construe therein; this concept is still in use today. LOS was expressed in terms of two performance measures: operating speed (governing performance measure) and volume capacity ratio (supplementary service measure.).

While developing the third edition of HCM average speed was considered as meager measure of the balance between passing demand and passing supply. In addition, despite the previous premise, average speed was found to be less sensitive to traffic flow rate. In addition to ATS, HCM 1985 thus familiarized a new performance measure, percent time delay (PTD), on two-lane highways. PTD was defined as "the average percent of time by which vehicles are delayed while travelling in platoons due to inability to pass." Vehicles are considered delayed while moving inside a platoon due to step down of speed from their desired speed. HCM 1985 adverted use of percent of vehicles with headways less than 5 s as a surrogate measure of PTD in field studies.

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The term "percent time delay" was somewhat improper because the criterion was not delay but time spent while travelling in platoons. HCM 2000 explained a more descriptive term, PTSF, which explains better the effect of platoon and lack of passing opportunities on two-lane highways. The PTSF is term which is defined as "the average percentage of travel time that vehicles must travel in platoons behind slower vehicles because of an inability to pass." To compute PTSF, the HCM suggests a surrogate field measure of the percentage of vehicles in the traffic stream with headways less than 3 s. For high-class (Class I highways), ATS was let an auxiliary performance measure as it makes LOS sensitive to design speed. For Class II, the performance is measured by PTSF alone. Because motorists' expectation is considered lower on Class II highways than on Class I highways, a further increment of 5% to the PTSF threshold, was made for Class II highways. As the rate of flow at the upper limit of a given LOS is higher in HCM 2000 than in HCM 1985, that's why the headway criterion was lowered from 5 to 3 s. For level and rolling terrain, analysis method laid down was extended by two-way segment methodology whereas, for specific upgrades and downgrades, it was directional segment method given by HCM. The latest edition, HCM 2010, represented directional segments analysis procedure in general terrain (level or rolling) as well. On the basis of wide range of functions provided, two-lane highways were classified into three categories: Class I, Class II and Class III. The first two classes, similar with the earlier classification, explain rural two-lane highways, while Class III highways are defined as the portions of rural highways that serve passably developed areas (small town or developed recreational areas). The Florida Department of Transportation formulated the analysis approach for these highways by updating the rural highway method. The best contribution of this edition was that it provided distinguishable performance measures by taking automobile and bicycle mode into consideration. Rife ATS and PTSF conception continued unedited, except that an introduction of a new measure, percent of free-flow speed (PFFS), was found appropriate on Class III highways, where passing restrictions are not a major issue, but drivers are expected to make steady progress at or near the speed limit. However, perception model and assessed by bicycle LOS (BLOS) score defined bicycle levels of service for two-lane highway segments .Threshold values of PTSF and ATS correspond to the previous edition but the adjustment factors to conclude these measures were appropriately modified.

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II. EVALUATION OF HCM MEASURES: STUDY CHRONICLE

Number of researcher followed the tradition of HCM; researcher (De Arazoza & McLeod, 1993; Brilon et al., 1994) suggested the use of Average Travel Seed as a service measure in computing LOS. In developed areas of the United States, De Arazoza and McLeod (1993) suggested ATS as the main LOS criterion for flow without interruption conditions. Brilon et al. (1994) described that the LOS assessment on German two-lane highways is based on ATS. In Finland, Luoma and Jaatinen (1999) considered both ATS and the predictability of travel times as performance measure for goods transport. However, a couple of international studies (Brilon & Weiser, 2006; Al-Kaisy & Karjala, 2008) made it evident that lack of a reference point along a performance scale is a major limitation of using ATS and makes performance comparison across sites unrealistic .

In support of the German experience on two-lane highways, Brilon and Weiser (2006) revealed the use of average speed of passenger cars as a notable performance measure. This could be calculated over a longer stretch of highway, contemplate the average of both directions. This was further investigated by Al-Kaisy and Karjala (2008) on four two-lane highway study sites in the state of Montana. Moreover, they proposed the use of ATS as PFFS (percent free flow speed) and ATS of passenger cars as PFFS of passenger cars. The functional relationship of these measures with the platoon variables was ostensibly not observed to be strong.

The headway criteria embraced in the third edition of HCM (HCM 1985) was investigated further for more practical estimation of PTD. For the estimation of proportion of delayed vehicles, Guell and Virkler (1988) suggested headways not more than 3.5 or 4 s and Luttinen (1992) suggested headways not greater than 3 s. Besides this, to describe service quality on two-lane rural highways Botha et al. (1994) announced the use of PTD as a measure. According to the subsequent edition of HCM assumed, PTSF to be more appropriate as performance measure and was given more attention in later research . Several studies (Luttinen, 2001; Harwood et al., 2003; Pollatschek & Polus, 2005) reported that the method suggested by HCM to determine PTSF overestimates the values. Luttinen (2001) proposed various models to estimate PTSF based on the percentage of no-passing zones, total flow and directional distribution of traffic. These models gave lower value of PTSF than that estimated by HCM. Based on a study conducted on unpredictability in the operational analysis of two-lane highways, Luttinen (2002) showed there were restraints in the accuracy of the analysis procedures which cause errors and lessen the usefulness of the LOS concept. According to Dixon et al. (2002) the HCM 2000 two-lane highway analysis procedures using the TWOPAS simulation model and field data collected from northern Idaho. The PTSF values of one-directional procedure were discern to be overestimated by both simulation models: it was about 10 % overestimation and about 30 % overestimation in the field data. He found, the values of two-way procedure were observed to be more accurate as compared to those of one-directional method. Subsequent to this research, Harwood et al. (2003) supervised the National Cooperative Highway Research Program Study on the HCM's two-lane road analysis methodology and prudent an overestimation of PTSF by HCM. Accordingly, there was formulation of revised set of curves to estimate PTSF. Based on an analysis of drivers' restiveness on two-lane rural highways, Pollatschek and Polus (2005) flourished theoretical models for turning down the critical passing gap with longer delays prior to the passing maneuver. The impatience of the driver may cause willingness to accept more precariousness because delay increases, which eventually reduces PTSF. This could be one major reason for overestimating the PTSF parameter by HCM. In a paper on the German experience, Brilon and Weiser (2006) reported that, in Germany, the PTSF has never been imprudent a substantial measure of effectiveness as it does not directly convey the degree of efficiency of traffic operation. Polus and Cohen (2009) evolved a queuing model to evaluate PTSF from the field data. This was used in a study supervised on 15 two-lane rural highway sections in northern Israel, and the actual PTSF values acquired from the study were also observed to be considerably lower than the corresponding HCM values. In another study, Cohen and Polus (2011) found similar lower values of PTSF and provided ameliorate relationship between PTSF and two-way flow by pertinent the new estimates by means of the least-squares method. Bessa Jr and Setti (2011) recalibrated the HCM 2000 ATS and PTSF functions for Brazilian roads using a genetic algorithm. These new models were able to better represent the behaviour of traffic streams. In a recent paper, Rozenshtein et al. (2012) reported that they calibrated PTSF models using actual field data collected on 84 one-way segments of two-lane rural highways in Israel and juxtapose those with HCM and other empirical models proposed in the past. Following the trend of past research, they also concluded noteworthy overestimation of the PTSF values, particularly during moderate- and low-flow condition. Meanwhile, Morrall and Werner (1990) put forward the use of overtaking ratio, which is obtained by dividing the number of passing achieved by the number of passing desired, as an indicator of LOS on

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two-lane highways; Romana and Pérez (2006) indicated an alternative way of using the HCM 2000 performance measures, that is, ATS and PTSF for evaluating the LOS on two-lane highways. On the basis of a study conducted in Egypt on evaluation of operational performance, Hashim and Abdel-Wahed (2011) defined seven performance measures and three platoon variables. Out of all they found follower density performance measure to have the strongest correlations to platoon variables.

III. ALTERNATIVE SERVICE MEASURES FOR TWO-LANE HIGHWAYS

In response to the clampdown of the existing practice in estimating PTSF as performance measure for two-lane highways, especially the complicated associated with its direct field measurement and divergences among the HCM procedures, lot of researchers concluded other alternative service measures. In order to explore for alternative service measures for two-lane highways in South Africa, Van As suggested follower density (number of followers with short headways per unit length) as a new and best performance measure for two-lane roads in South Africa. In the same study, the author scrutinized other service measures of which included are percent followers (proportion of vehicles with short headways), total queuing delay percent speed reduction due to traffic, followers flow (number of followers with short headways per hour) and traffic density. Out of all, follower density was also recommended as good service measure for two-lane highways based on studies conducted in Idaho and Japan .Another indicator recommended was threshold speed as alternative performance measure for two-lane highways, specifically, a substitute for PTSF . Other proposed alternative service measures for the road class under discussion include Average travel speed of passenger cars, Average travel speed, Average travel speed as percentage of free flow speed of passenger cars, Average travel speed as percentage of free flow speed, Percent followers and Percent impeded . The advantages and drawback of these proposed measures are discussed as follows:

Threshold Speed: It is defined as the minimum speed drivers assume satisfactory while traveling on a uniform section of a carriageway under heavy and platoon traffic whose value is based on user perception and good judgment . Although this indicator is easy to measure, yet it is complicated to assign a particular cut-off speed acceptable to all users. For example, what a patience driver consider as an acceptable speed, an aggressive driver may not. therefore, this measure is more of user bias.

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Follower Density (FD): It deals with the number of directional followers with short headways per unit length, usually 1 kilometer or mile. The main advantages of this measure are it accounts for freedom to maneuver and congestion level in the traffic stream . A major limitation of this indicator is that it is does lend itself easy to measure in the field, as such it is usually derived from flow rate and speed from spot measurements despite it is a space related measure.

IV. AVERAGE TRAVEL SPEED OF PASSENGER CARS (ATSPC)

ATSPC is a service measure in Finland and Germany because the indicator more precisely describe lowering in speed which is a result of traffic as ATSPC are more affected by high volumes of traffic . ATSPC has the same advantages and weakness as those of ATS.

V. AVERAGE TRAVEL SPEED (ATS)

ATS is one of the best methods used by HCM. This method is considered as a good performance indicator for two-lane roads as it relates well with user perception and also very easy to measure as compared to other methods. However, its key limitation is lack of specific yardstick across the performance level due to variations in two-lane highways in terms of operating speeds and geometry. Thus, using ATS individually may not explicitly describe the performance without a reference point.

VI. AVERAGE TRAVEL SPEED AS PERCENTAGE OF FREE FLOW SPEED (ATS/FFS)

This method is measure of the extent of speed diminutions due to traffic. A high percentage of ATS/FFS represents a minimum vehicular interaction and high performance. The opposite of this results in high vehicular interaction and low level of service. Like ATS, ATS/FFS is also easy to measure in field but lack definite benchmark regarding the level of interaction between the vehicles in the traffic stream as against PTSF in HCM which specified a cut-off headway value.

VII. AVERAGE TRAVEL SPEED AS PERCENTAGE OF FREE FLOW SPEED OF PASSENGER CARS (ATSPC/FFSPC)

This measure is similar to ATS/FFS except that heavy vehicles were excluded in the speed measurements. The use of this indicator is based on the rationale that passenger cars are more sensitive to speed reduction due to traffic as their speed are more affected by high traffic volumes than those of heavy vehicles. ATSPC/FFSPC is also easy to measure in the field but has the same limitation as that of ATS/FFS.

VIII. PERCENT IMPEDED (PI)

PI is referred to as the percentage of vehicles hampered by slower moving vehicles in traffic stream measured at a particular point. When we compare PI with other service measures, PI relatively correlates well with other measures and platoon variables excluding traffic volume.

IX. PERCENT FOLLOWERS (PF)

This measure indicates the proportion of vehicles with low headways in a traffic stream. The indicator can be measured in the field in the same way concluded by HCM using 3 s. A key drawback of solely using PF as service measure is that it does not reflect the consequences of traffic level which is a vital condition in HCM LOS concept. Theoretically, low traffic levels could still yield high PF if speed variation is relatively high and passing opportunities are restricted. Consequently, the use of PF alone could be misleading. Another weakness of the indicator is that it is measured based on spot observation and assume applicable over long section.

X. DISCUSSIONS

On the basis of existing literature and/or various studies reviewed in this paper, it is perceptibly corroborate that the HCM analytical and field observation procedures for estimation of PTSF do not produce stable results. In fact, the analytical procedures created overestimated values; or the field observed values based on 3 s surrogate measure were generally less than those according to the analytical estimates. An extract of an approximate overestimation of PTSF values by the HCM two-way analytical procedure relative to field data [6, 14, 15] at 1000, 2000 and 3000 flow rates (PCUs/hr) is presented in Table 1. The results represented that even at same values of flow rates, the level of overestimation dissimilar from one study to the other. At flow rate of 1000 (PCUs/hr), an overestimation of about 12%, 24%, 19% and 20% were observed. At the same flow rate, Van As and Van Niekerk PTSF field estimates were consistently lower than those according to HCM curve. Similar changes in PTSF overestimations were recorded at flow rates of 2000 and 3000 (PCUs/hr) respectively. Using the same procedure, an average overestimation of about 23% was recorded. As the result of directional analysis procedure is an overestimated PTSF values relative to field observed values. As is the case with the two-way analysis approach, different levels of overestimation were observed in various studies.. PTSF values recorded in South African study based on field observation and model developed were also comparable with those of other studies mentioned earlier. While other studies observed overestimation of PTSF for all values of flow rates (except zero) by HCM model relative to spot observed values, pattern was observed different in the case of HCM model.

Table 1: Approximate Overestimation (%) of PTSF by HCM Two-Way Analysis Relative to Field Values For Selected Flow Rates (PCUs/hr)

Study	Flow Rate (PCUs/hr)		
	1000	2000	3000
Finnish Model	12	13	10
Exponential Model	24	26	22
Polus & Cohen	19	19	15
Polus & Cohen	20	21	16

For the HCM analytical and field observation procedures to represent each other, PTSF estimates from the two approaches should at least be approximately the same if not equal. To date, the question as to which procedure is more accurate is still ambiguous. Overestimation by the analytical procedures could be as result of heavy reliance on simulations while developing the models which involved a lot of assumptions pertaining traffic characteristics; especially drivers' behaviour in performing overtaking performance. Likewise, the consistent low values of field observed PTSF using the 3 s headway relative to the analytical method estimates could be as a result of the fundamental assumption that spot observed values show long segment estimates. This could probably be true for short straight sections on level terrain with sufficient sight distance and passing opportunities. Field conditions different from these; such as road sections with inadequate sight distance and involving sizeable proportion of hilliness and bendiness could result in higher value of PTSF. In other words, the field spot observation may not precisely take care of the influence of these characteristics as they could cause considerable reducing effects on passing opportunities on two-lane highways; which would consequently results in longer time spent following. Thus, measuring PTSF along the segment may produce results that are closer to reality as opposed the current practice of spot measurement and assume to represent time spent following along a stretch of the road.

The present unanswered question on the estimation of PTSF based on the current practice of 3 s rule is that whether the 3 s cut-off headway used for field observation at given spot really represents the actual time spent following over a long section of two-lane highway or not? While researchers corroborated that HCM equations overestimate PTSF values as compared with those obtained based on spot observation in the field using 3 s as surrogate measure, the level of overestimation varies from one study to the other. Moreover, neither the HCM, nor other studies indicated an acceptable difference or error between estimates from the two approaches. Hence, this lack of boundary on acceptable errors among the procedures left users with the choice of an approach they feel more comfortable with and not minding the accuracy of the chosen method and this could be misleading. The authors of this paper are therefore on the opinion that provision of alternative method for field estimation of PTSF along two-lane highway's segment could be more realistic and also substantiate the application of the existing practice.

XI. CONCLUSIONS AND SUGGESTION FOR FURTHER STUDY

Utilization of PTSF by HCM as service measure for two-lane highways faces denunciation from numerous researchers not because of its paucity as performance indicator; simply because, it is complicated to measure directly in the field. Also, the two approaches for evaluating PTSF; analytical procedures and use of 3 s surrogate measure for field observations were corroborate to produce inconsistent results. In fact, the analytical procedures notably overestimate PTSF as juxtapose to field values. The point here is not about questioning the criterion of using 3 s as a surrogate measure for field estimation of PTSF as the cut-off headway has been widely judged satisfactory, but it is about the procedure used in applying the criterion. For the fact that PTSF is a segment related measure, the authors contend its observation at representative point and its applicability over a long section of two-lane road. Although, some other studies proposed the use of other service measures for evaluating the performance of two-lane highways; yet it is equally important to search for alternative method that is devoted to reality for field measurement of PTSF. Chiefly, one that would observe the indicator in the

field along the road's segment as opposed the current practice of spot observation and considered as representative of a long section. Coming up with an alternative method for field measurement of PTSF along road segment will serve as a basis to justify the application of the 3 s headway criterion at representative point.
Since PTSF is travel time related evaluation, the most likely way to evaluate the indicator along a road segment is to use the observer(s) within the traffic stream under study. This could be achieved through when one uses test vehicle (moving car observer) technique. Hence, the authors suggested the use of test vehicle approach over the highway segment to be evaluated to identify the variables that are vital for the development of a representative PTSF measurement model. This would enable the estimation of PTSF over a segment based on actual time spent following as against the existing practice of using surrogate measure on the basis of local platoon. It is hoped that this review and suggestion offered on the alternative method for field measurement of PTSF along segment will impart basis to substantiate the current practice of evaluating PTSF based on spot observation and bestow in advancing the performance analysis of two-lane highways.

The above studies, however, do not consider the effect on performance measures when the traffic is heterogeneous in character. This is noteworthy in developing countries, where heterogeneity in traffic mix is extensive. Even the traffic composition occasionally consists of countable percentage of non-motorized traffic. As a repercussion, large speed variation in the traffic stream becomes one of the vital factors for frequent platoon formation and affects performance measures. The present study evaluates the HCM measures using actual field data comprising considerable proportion of slower vehicles collected on two-lane highways in northeast India; this has been a matter of great concern to the engineers analyzing traffic flow on these roads.

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