Available online at www.sciencedirect.com

ScienceDirect

Procedia - Social and Behavioral Sciences 104 (2013) 440 – 448

Procedia
Social and Behavioral Sciences

2nd Conference of Transportation Research Group of India (2nd CTRG)

Operational Performance Measures for Two-Lane Roads: An Assessment of Methodological Alternatives

Indrajit Ghosh[a,]1, Satish Chandra[b], Amardeep Boora[c]

[a]*Assistant Professor, Department of Civil Engineering, IIT Roorkee, Roorkee 247667, Uttarakhand, India*
[b]*Professor, Department of Civil Engineering, IIT Roorkee, Roorkee 247667, Uttarakhand, India*
[c]*Ph.D. Student, Department of Civil Engineering, IIT Roorkee, Roorkee 247667, Uttarakhand, India*

Abstract

Two-lane roads represent the majority of the highway system in India. The analysis of traffic performance on two-lane roads is critical for their planning, design, maintenance, rehabilitation, and operation. It is a major input to important decisions on public fund investments that are made at different stages of the highway life. Performance evaluation is typically carried out with the capacity analysis for various highway facilities. Many countries in the world have a standard methodology for capacity analysis procedure. In general, performance of a highway is expressed in terms of level of service (LOS), which is a scheme intended to depict traffic conditions for an existing or proposed transportation facility operating under current or projected traffic demand. Evaluating the performance of the two-lane roads is not an easy task because of several distinct characteristics associated with these roads. IRC: 64-1990 provides some guidelines for capacity of two-lane roads; however, these guidelines provide very little information on LOS and its evaluation on these roads. As a result of that planners in India use the methodologies given in the Highway Capacity Manuals (HCM) of other developed countries. But these methodologies may not be applicable for Indian mixed traffic condition. This adoptation can cause serious consequences in situations where capacity augmentation by widening of the roads will cost huge amount of money. Therefore, it is necessary to examine the concerns expressed above and evaluate operational performance measure(s) used by researchers across the globe which would be appropriate and applicable to Indian conditions. This paper summarises the evolution of research on determining the LOS of two-lane roads and provides a discussion for future directions pertinent to Indian mixed traffic situation.

Keywords: two-lane roads; level of service; performance measures; volume to capacity ratio; percent time spent following;

* Corresponding author. Tel.:+91-1332-285533; fax: +91-1332-275568.
E-mail address: indrafce@iitr.ernet.in, indrajitghosh29@gmail.com

doi:10.1016/j.sbspro.2013.11.137

1. Introduction

Major portion of the highway system in India consists of two-lane highways. As per the latest status obtained from MORT&H (2012), two-lane roads comprised of approximately 54 percent of the total length of Indian national highways. For the planning, design, maintenance, rehabilitation, and operation of these roads, it is very important to analyse the traffic performance on those facilities. Evaluation of the traffic performance is a key input to significant decisions on public fund investments carried out at different stages of the highway life. Performance evaluation is usually conducted with the capacity analysis for various highway facilities. Various countries in the world have developed standard methodologies for capacity analysis procedure. In most cases, performance of a highway is expressed in terms of level of service (LOS), which is a method proposed to illustrate traffic conditions for an existing or proposed transportation facility operating under current or projected traffic demand. Except providing some guidelines for capacity of two-lane roads, Indian standard (IRC: 64-1990) offers too little information related to LOS and its evaluation on these roads. Therefore, the planners use the methodologies as given in the Highway Capacity Manuals (HCM) of other countries (HRB, 1950, 1965; TRB, 1985, 2000, 2010) particularly of the developed ones; which may not be applicable for Indian mixed traffic condition. These can result into serious consequences in the circumstances where capacity augmentation by widening of the roads will cost huge amount of money. Therefore, it is necessary to examine the above concerns and identify operational performance measure(s) which would be appropriate and applicable to Indian conditions.

Evaluating the performance of the two-lane roads is not an easy task because of some distinct characteristics associated with these roads. As these roads are comprised of only one lane in each direction for the movement of traffic, at areas with higher traffic volume they experience high level of interaction between vehicles both in the same as well as opposite direction. Vehicles generally overtake the leading slower vehicles using the opposing lane when proper sight distance and gaps in the opposing flow are available. This maneuver also depends on the risk taking level of the drivers. Platoon is found to form in case of inadequate overtaking opportunities. While some of the vehicles move in platoon depending upon the volume level in each direction, others travel in between the platoons with no speed impedance. Motorists on a two-lane highway with low volume seldom get delayed, but as volume approaches capacity, proportions of vehicles in platoon increase and higher delay is experienced. As the ability of motorists to overtake goes down, motorists are compelled to adjust their speed perceiving reduced quality of service. In order to avoid long platoon, motorists prefer to travel between platoons and demonstrate more risk taking behaviour while performing the overtaking maneuver. Consequently, this phenomenon affects the traffic operations and safety along two-lane roads. Setting these aside, the heterogeneous traffic condition in India where fast moving and slow moving vehicles with various size, power, control and performance capability are sharing the same roadway makes the situation even more challenging. The current study aims at reviewing the evaluation of the performance of two-lane roads when the facility is being used by heterogeneous traffic. This assessment will help to illustrate the quality or level of service perceived by the motorists traveling on these roads.

2. Background Studies

From the time motorised transportation started, traffic and transportation engineers have been trying to find the different ways to define capacity of transportation facilities. But only defining the maximum performance of the system was not enough; Engineers were also concerned about the traffic conditions experienced by the road users. In order to define the quality of flow in a reliable manner, engineers have tried to use various performance measures and concepts that can be easily understood by road users. An appropriate performance measure is able to define the perception of the users utilizing the facility and help engineers to analyse them (Luttinen, 2001c). At present, mostly two methodical tools are being used across the world to analyse the performance of two-lane roads, 1) Highway Capacity Manual (HCM) defined analytical procedures, and 2) Microscopic traffic simulation

models, such as TWOPAS, which is utilised sometimes to match with the HCM procedures. Two-lane roads are present in rural, suburban, or urban areas and have a wide range of operational characteristics. The current study aims reviewing different performance measures describing the traffic flow quality on two-lane rural roads that have been identified and utilised by various researchers around the globe.

2.1. Studies carried out up to year 2000

In the process of defining traffic capacity and quality of traffic flow on two-lane roads, historically HCM (HRB, 1950) of USA was the first document to develop an analytical procedure for capacity analysis. It serves as the national reference in USA for the purpose of capacity analyses on highways and other transportation facilities. 1950 version of HCM (HRB, 1950) stated that overall speed is the most important traffic congestion index for different flow rates. It also identified passing opportunities as a congestion index. This manual defined practical capacity by comparing the desired number of passing with actual passing at different volume levels for estimating the capacity for two-lane roads. The next version of HCM (HRB, 1965) presented the concept of LOS by extending upon the idea of practical capacity to evaluate the quality of road service as perceived by users. This procedure was based on speed-flow relationship. A qualitative measure was chosen to represent the quality of service provided to motorists on a particular facility type. Relationships between the service measures and traffic flow rate were developed. Six levels of service A to F were defined where LOS E corresponded to capacity conditions. The two service measures which were used to find out LOS were operating speed and volume to capacity (v/c) ratio. The capacity for two-lane roads was found to be 2000 passenger car per hour (pcph) for both directions of travel, irrespective of directional splits. Latter version of HCM (TRB, 1985) defined LOS as a qualitative measure which elucidates operational conditions within a traffic stream and road users' perception about them in terms of several factors such as speed, travel time, freedom to maneuvre, traffic interruptions, comfort, convenience and safety. The 1965 HCM included operating cost as a LOS measure, but as no extensive research has ever been carried out to relate this factor to service quality, it was eliminated in 1985 HCM. Similar to 1965 HCM, the 1985 HCM did not consider flow as a LOS measure. To describe the LOS for two-lane roads, it started using average travel speed (ATS) and a new measure known as percent time delay (PTD). While the length of the highway segment divided by the average travel time of all vehicles traversing the segment, including all stopped delay times has been termed as ATS, average percent of time that all vehicles are delayed while traveling in platoons due to inability to pass has been described as PTD. Delay referred to the situations where motorists traveled behind a platoon leader at speeds lower than their desired speed and at headways less than 5 seconds. The percentage of vehicles that satisfied these criteria was used as a surrogate measure to PTD. It was found that capacity is a function of directional split of traffic, ranging from 2800 pcph (total in both directions) for a 50/50 directional split to 2000 pcph for a 100/0 split (i.e., all traffic in one of the two directions).

Wong and Morrall (1987) found out that PTD is not a good surrogate measure of overtaking based upon results obtained from series of simulation tests and field observations. They concluded that PTD cannot serve as a perfect measure of LOS. Consequently, Morrall and Werner (1988) recommended the use of overtaking ratio as an auxiliary indicator of LOS, which can be calculated as the number of passing achieved divided by the number of passing desired. The number of passing achieved is the total number of passing for a given two-lane highway, while the number of passing desired is the total number of passing for a two-lane highway with continuous passing lanes and similar vertical and horizontal geometry. It was found out that overtaking ratio decreased much faster in comparison to increase in PTD for the ranges of level of service defined by 1985 HCM.

To identify the pros and cons of the existing operational analysis procedures, Harwood et al. (1999) conducted a review of 1985 HCM which remained same in the 1994 and 1997 updates in HCM. They considered the confusion of HCM users regarding the definition of the PTD, which was used as the service measure along with inconsistency between the LOS assessments made with the general terrain segment and specific grade procedures. They also investigated the lack of an effect of roadway design speed on LOS and lack of a procedure

to calculate the operational effects of passing and climbing lanes. For this purpose, data were collected from 20 different sites and a TWOPAS model was used to provide a valid and useful tool for computer simulation of traffic operations on two-lane highways. PTD was renamed as Percent time spent following (PTSF) which is described as average percentage of travel time that vehicles have to travel in platoon following slower vehicles because of their lack of ability to pass. While ATS reflects the mobility function, PTSF corresponds to freedom to maneuver as well as road users' comfort and convenience during travel on a two-lane highway which are two important aspects of the LOS concept. Measurement of PTSF directly from the field is a tedious task, and therefore based upon the TWOPAS model it was decided to calculate PTSF as the percent of vehicles traveling at headways of 3 seconds or less at a particular point on the roadway segment. Next version of HCM (TRB, 2000) incorporated these changes and used PTSF and ATS as service measures for Class I highways (roads with relatively higher speed) as shown in figure 1, and only PTSF for Class II highways (roads where motorists do not expect to travel at higher speed, which provide access to Class I roads and serve short trips) as shown in table 1 below. This classification of two-lane roads was based on motorist expectation rather than highway functionality. As per HCM 2000 (TRB, 2000), PTSF can be determined by considering two-lane roads as two-way segments or directional segments with or without passing lanes. The maximum flow rate defined by HCM 2000 (TRB, 2000) on two-lane roads in one direction was 1700 pcph and it did not exceed 3200 pcph for both directions of travel combined.

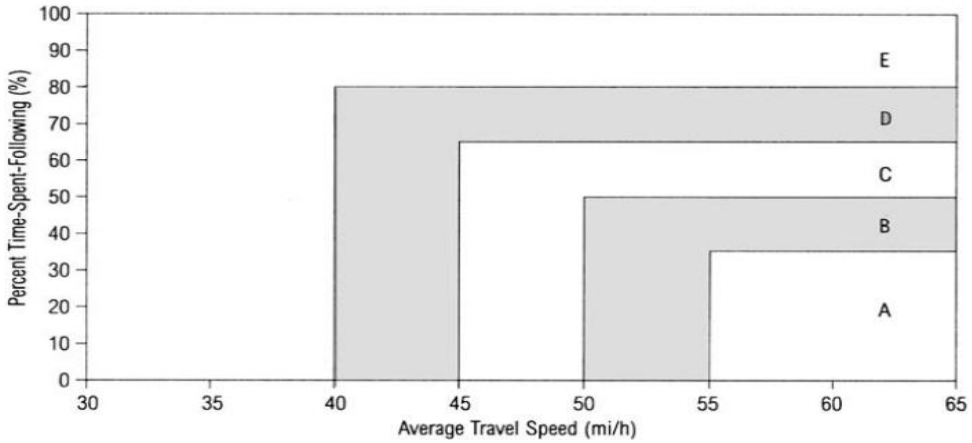

Fig. 1. LOS criteria for Class I two-lane highways (HCM, 2000)

Table 1. LOS criteria for Class II two-lane highways (HCM, 2000)

Level of service	Percent time spent following
A	≤40
B	>40-55
C	>55-70
D	>70-85
E	>85

Note: LOS F refers to the situations where flow rates exceed the segment capacity.

2.2. Studies conducted between 2001 and 2005

After HCM 2000 (TRB, 2000) procedure was introduced, researchers in US and particularly the ones in other countries carried out studies to assess the new procedures of evaluating traffic performances on two-lane roads. These types of research comprised of both theoretical and empirical validation of the HCM 2000 procedures. In order to define LOS on Finnish two-lane roads, Luttinen (2000, 2001a) used data obtained from 20 automatic traffic recorders (ATRs) in the summers of 1997 and 1998 for 15 minute time intervals. Effect of heavy vehicles was eliminated by using refined passenger car flow rates. Both linear and concave speed-flow models were estimated. It was observed that speed reduction due to increasing flow rate was smaller on Finnish highways in comparison to the HCM 2000 estimate. A linear relationship was also established between directional capacity and opposing flow rate. The effect of the flow rate was found out more than the effect of opposing flow on ATS. The study suggested that directional distribution should be considered for determining ATS. In another study, Luttinen (2001b) gave an overview on traffic flow on two-lane highways in Finland. It was found out that when numbers of heavy vehicles increased the demand of passing and platooning also increased in the same direction of flow of heavy vehicles. Due to the no use of free space in opposing lane by major flow, it was found that density was not an effective measure for two-way flow on two-lane roads. The two-lane highways analysis was founded upon directional analysis and also conformed to HCM 2000. Effect of directional distribution was found out in random traffic for two-way PTSF. A speed-flow curve was obtained with a steeper slope in case of high free flow speed by studying standard deviation of ATS. It was found out that when flow rate of heavy vehicles increased then the marginal impact of heavy vehicles decreased. In a separate study, Luttinen (2001c) analysed PTSF as a performance measure of two-lane roads by collecting data from two-lane highway in Finland. Using this data which was based on traffic volumes in the observed and opposing directions, a model was developed to determine PTSF. It was found that HCM 2000 overestimates PTSF for Finnish two-lane roads and calibration needs to be carried out for local condition. Additionally, PTSF measured from the directional analysis were found to be higher than those measured from the two-way analysis.

Dixon et al. (2002) tried to validate the HCM 2000 procedure by using data collected at five locations along US-12 in the state of Idaho, USA. They used the term percent following (PF) for the HCM 2000 defined surrogate field measure of percentage of vehicles with headways less than three seconds TWOPAS simulation model was utilised in order to have additional insight. Inconsistencies were noticed between directional and two-way analysis procedure of PTSF estimate. Two-way analysis was found to be superior in terms of accuracy, though both of the procedures along with TWOPAS estimates produced PTSF estimates which were substantially higher than the PF estimate observed from field data.

Van As and Van Niekerk (2004) examined various performance measures as a part of developing new methodology and simulation model for two-lane roads in South Africa. The developed model utilised queuing theory to simulate the change in queue or platoon length over the length of a road. Among different performance measures, follower density (number of followers per km per lane) showed maximum potential as it incorporates three different performance measures into one, namely, percentage followers, traffic flow and travel speed. Thus, this measure of effectiveness (MOE) can provide better idea about the situations when capacity upgrading is warranted.

2.3. Studies conducted between 2006 and 2010

Romana and Perez (2006) used threshold speed value to measure LOS in Spain for two-lane roads which was defined as the minimum speed accepted by road user while traveling on a uniform road section under heavy flows and platooning traffic. For the study MOEs as defined in HCM 2000 were used. It was found that PTSF is required to be calculated only when ATS is greater than some threshold value, otherwise platooning would be

behind speed in importance in the view of drivers. The results carried out from the study were found out to be very close to driver perception.

Durbin (2006) carried out a study to find out PTSF by using two new methodologies, namely, weighted-average approach and probabilistic approach as it was considered that the methods used in HCM 2000 were not appropriate to find out the performance on two-lane roads. The weighted-average approach was intended to estimate PTSF by classifying the vehicles as per their performances and assessing their effect on the traffic stream. The probabilistic method was used to estimate PTSF by finding out the probability of vehicles traveling unwillingly within a platoon at a speed lower than their desired travel speed. For testing these two approaches, data were collected from the three different sites in Montana, USA. The study found that when the number of vehicles inside a platoon increased, the mean travel speed of the platoon reduced. Vehicle travel speeds and time headway were observed to have a direct relationship among them. Travel speed went up when the time headway increased up to 6 seconds, beyond which the relationship flattens as there was not so much increase in speed with the increment of headway values. Weighted-average approach performed the best when vehicles were classified by their performance. Comparison with the HCM 2000 method revealed that both the methods can provide lower values of PTSF, thus these two methods displayed the potential of eliminating the overestimation observed with the HCM 2000 procedures. The probabilistic approach was found to be superior as it constantly showed better performance in comparison to the weighted average method. PTSF value estimated from the probabilistic approach was observed to be very sensitive to traffic volume, its temporal variations, heavy vehicles percentage, and the effect of passing lanes.

Brilon and Weiser (2006) analysed traffic performance on two-lane roads in Germany. They used density (the traffic volume divided by average travel speed of passenger cars) as a MOE for defining the LOS for two-lane roads. In Germany, PTSF had never been considered as a significant MOE as it lacks the ability to directly convey the degree of efficiency of traffic operations on two-lane roads. A simulation model was calibrated to produce speed-flow diagram for all the types of two-lane rural roads. A density of 40 vpkm was found to be the typical critical threshold beyond which traffic breakdown occurred. This service measure of density has been incorporated in German Highway Capacity Manual also.

Various performance measures were used by researchers at Montana State University (Al-Kaisy and Karjala, 2008; Karjala, 2008) to investigate performance on two-lane roads which were average travel speed, average travel speed of passenger cars, average travel speed as a percent of free-flow speed, average travel speed of passenger cars as a percent of free-flow speed of passenger cars, percent followers, and follower density. Using graphical screening, correlation, and regression analysis methods, a number of relationships were established between performance indicators and major platooning variables. It was found out that follower density has highest correlation with platooning variables. It considered traffic level and can be estimated easily in field in comparison to PTSF. This study found follower density to be a potential service measure on two-lane roads followed by percent followers.

Theoretical and empirical relationships were developed by Polus and Cohen (2009) for measuring the quality of flow and for a new LOS measure on two-lane highways. For this purpose five different parameters pertinent to estimation of the flow characteristics on these highways were considered, namely, flow, traffic intensity (ratio between the average time spent in the first position when waiting for an appropriate gap and average inter-arrival times at the back of the queue), average platoon length, PTSF and freedom of flow. PTSF was measured directly by estimating number of headways inside and outside the platoon. PTSF turned out to be an appropriate measure to estimate LOS and evaluate delay costs because it can assist in the calculation of the time lost in platoons which again can be translated to monetary values. This method was a bidirectional approach because all parameters were dependent on the opposing flow.

Next version of HCM (TRB, 2010) classified the highways in three different classes which are Class I, Class II and Class III. LOS was categorised on the basis of these classes by using different parameters, namely, ATS, PTSF and percent of free flow speed (PFFS). The new parameter included in this version of HCM (TRB, 2010),

PFFS, characterizes vehicle's ability to travel at or near the posted speed limit. On Class I roads, LOS was defined by using ATS and PTSF as both speed and delay are considered crucial for the drivers due to their inability to pass. For Class II highways, travel speed is not a big issue for drivers, so LOS was defined by using PTSF only. Class III highways serve moderately developed areas; their lengths are limited implying little concern for passing restrictions. For these highways, no high speed is expected and driver wants only steady progress at or near the speed limit. So, PFFS was used to define LOS. The LOS criteria for two-lane highways are shown in table 2 below. In addition to these 5 LOS classes (LOS A to E), LOS F was referred to the situations when flow rates exceed the segment capacity depicting unstable operating conditions, and heavy congestions.

Table 2. LOS criteria for two-lane highways (HCM, 2010)

Level of service	Class I Highways		Class II Highways	Class III Highways
	ATS (mi/h)	PTSF (%)	PTSF (%)	PFFS (%)
A	>55	≤35	≤40	>91.7
B	>50-55	>35-50	>40-55	>83.3-91.7
C	>45-50	>50-65	>55-70	>75.0-83.3
D	>40-45	>65-80	>70-85	>66.7-75.0
E	≤40	>80	>85	≤66.7

Al-Kaisy and Freedman (2010) used a new measure, percent impeded (PI), to calculate performance on two-lane highways. PI represents the percentages of vehicle which are impeded by slower vehicles in traffic stream due to the formation of platoon. Several other measures were also considered, namely, percent followers, follower density, and ratio of average travel speed to free-flow speed, and their relationships were investigated by using regression analysis. Data were collected from two-lane highways with passing lanes in the state of Montana. To examine the effect of traffic and geometric variables on platooning on two-lane highways, two distinct analyses before-and-after passing-lane analysis and downstream performance analysis were carried out. For the former analysis, PI showed more significant improvement in performance in comparison to percent follower and follower density. Speed ratio (ATS/Free flow speed) was found to be insensitive to platooning. PI established comparatively high correlation with other performance measures and platooning variables, except traffic volume. From the regression analysis, it was found that PI represented the strongest model as determined by the coefficient of determination, standard error, and significance testing results.

The impact of horizontal alignment on traffic performance at rural two-lane highways was studied by Shawky and Hashim (2010) by using the follower density as a MOE in place of PTSF which was difficult to observe in the field. The traffic data were collected from mid-tangent and mid-curve points at nine different sites with various horizontal alignment characteristics. A number of relationships were established between the follower density, flow rate, horizontal alignment characteristics (curve radius, tangent length), and average speed. It was observed that at the same flow rate the follower density increases as the curve radius or the tangent length decreases. They also analysed the differences between the follower density on the curves and adjoining tangents. The follower density was significantly affected by curve radius less than 400 m but no significant impact was found for curves with radius larger than 450 m. Consequently, a threshold value of the horizontal curve radius which fell between 400 and 450 m appeared to be a significant value from the traffic performance point of view.

2.4. Studies conducted after 2010

Hashim and Abdel-Wahed (2011) in Egypt established relationship between operational performance measures on rural two-lane roads and platooning phenomenon by using different performance measures, which were average travel speed, average travel speed of passenger cars, average travel speed as a percentage of free-

flow speed, average travel speed of passenger cars as a percentage of free-flow speed of passenger cars, percent followers, follower density, and percent impeded. The platooning phenomenon was represented by three variables, namely, flow in the direction of travel, opposing flow and percentage of heavy vehicles and it was found out that for Egyptian rural two-lane conditions, the follower density is a promising measure for studying operational performance.

3. Conclusions

Currently the operational analyses of two-lane highways in different countries are being conducted by using the methods described in Highway Capacity Manual (TRB, 2000, 2010). While the latest HCM (TRB, 2010) recommends the use of ATS, PTSF, PFFS for different classes of roads as performance measures, researchers in the United States and other countries found large discrepancies between performance measures obtained from HCM-defined analytical procedure and field data. Additionally, several studies outside United States have observed that the methodologies described in the HCM may not be appropriate or adequate for the local conditions. This could lead to situations where capacity expansions are undertaken on the basis of inadequate analysis. Consequently, new performance measures have been incorporated in the studies. The matter presented in this paper shows that all of these studies are based upon homogeneous traffic conditions, where the two-lane roads are mainly used by passenger cars, heavy and/or recreational vehicles. In India, the same kind of facilities are used by different types of road users, e.g., passenger cars, two-wheelers, three-wheelers, trucks, LCV, buses, etc. which makes the evaluation of the existing operational conditions of two-lane roads really challenging. LOS concept was first introduced in 1965 version of HCM (HRB, 1965). Indian standards, for example, IRC:64-1990 provides a qualitative speed-volume curve showing LOS with no details of its evaluation procedure. Few studies (Chandra, 2003, 2004a, 2004b) have evaluated capacity of two-lane roads under mixed traffic conditions by assessing the effect of several influencing parameters such as roadway factors, environmental conditions, traffic scenario, etc. on capacity. But no extensive works have been carried out in order to define LOS for two-lane roads based upon local conditions.

4. Recommendations

From the literature review, it is evident that many parameters have been used by researchers in order to define LOS on two-lane roads. It is also observed from the discussion that many of these parameters are difficult to measure in the field. For example, though PTSF has the ability to explain platooning effect and lack of passing opportunities realistically and thus can relate operational characteristics on two-lane roads well, yet it is not feasible to measure in the field. The HCM (TRB, 2000) therefore allowed the use of percentage followers (PF) as a surrogate measure for PTSF. Additionally, PTSF was found to be significantly overestimated by the HCM 2000 when compared to their counterparts from field measurements. It is interesting to note that the HCM 2010 procedures were developed relying solely on simulation results rather than empirical investigations. It was also observed that PTSF or PF only provide an indication of the LOS experienced by an individual road user and not the total service provided to all road users. Therefore, they cannot be used for purposes of warranting improvements such as capacity upgrades of a road. At the same time, under the mixed traffic condition it is really a difficult task to differentiate between the lead vehicle and follower one. Some of the parameters considered by various searchers for their studies can be measured easily. Example of such parameters are traffic density, average travel speed of passenger cars, average travel speed as a percentage of free-flow speed, and average travel speed for passenger cars as a percentage of free flow speed of passenger cars. For Indian traffic condition, in order to develop performance measures of two-lane roads trials should be made to correlate these parameters to the v/c ratio. Correlating the LOS with v/c ratio can make the performance evaluation of two-lane roads a relatively easier task and it can be easily understood and applied by the practicing field engineers.

References

Al-Kaisy, A., & Freedman, Z. (2010). Estimating Performance on Two-Lane Highways Case Study Validation of a New Methodology. *Transportation Research Record,* No. 2173*,* Transportation Research Board, National Research Council, Washington, D.C., 72-79.

Al-Kaisy, A., & Karjala, S. (2008). Indicators of Performance on Two-Lane Rural Highways. *Transportation Research Record,* No. 2071, Transportation Research Board, National Research Council, Washington, D.C., 87-97.

Brilon, W., & Weiser F. (2006). Two-lane Rural Highways: The German Experience, *Transportation Research Record,* No. 1988, Transportation Research Board, National Research Council, Washington, D.C., 38–47.

Chandra, S., and Kumar, U. (2003). Effect of lane width on capacity under mixed traffic conditions in India. *Journal of Transportation Engineering*, ASCE, 129(2), 155-160.

Chandra, S. (2004). Capacity estimation procedure for two-lane roads under mixed traffic conditions. Paper No.498, *Journal of Indian Roads Congress*, Indian Road Congress, New Delhi, 139-170.

Chandra, S. (2004). Effect of road roughness on capacity of two-lane roads. *Journal of Transportation Engineering*, ASCE, 130(3), 360-364.

Dixon, M. P., Sarepali, S. S. K., & Young, K. A. (2002). Field Evaluation of Highway Capacity Manual 2000 Analysis procedures for Two-Lane Highways. *Transportation Research Record,* No. 1802, Transportation Research Board, National Research Council, Washington, D.C., 125-132.

Durbin, C.T. (2006). Traffic performance on two-lane, two-way highways: examination of new analytical approaches. *A thesis submitted i*n Montana State University Bozeman, Montana

Harwood, D. W., May, A. D., Anderson, I. B., Leiman, L. & Archilla, A. R. (1999). Capacity and quality of service of two-lane highways. *NCHRP Final Report 3-55(3)*, Midwest Research Institute, University of California, Berkeley.

Hashim, I. H. & Abdel-Wahed, T. A. (2011). Evaluation of performance measures for rural two-lane roads in Egypt. *Alexandria Engineering Journal*, Elsevier, 50, 245–255.

HRB (1950). *Highway Capacity Manual: Practical Applications for Research*. Department of Traffic and Operations, Committee on Highway Capacity, Highway Research Board, United States Government Printing Office. Washington, D.C.

HRB (1965). *Highway Capacity Manual, Special Report 87, Publication 1328*. Department of Traffic and Operations, Committee on Highway Capacity, Highway Research Board, *National Academy of Sciences, National Research Council*, Washington, D.C.

IRC: 64-1990. Guidelines for capacity of roads in rural areas. First Revision. Indian Road Congress. New Delhi.

Karjala, S. R. (2008). Estimating quality of traffic flow on two-lane highways. *A thesis submitted* in Montana State University Bozeman, Montana.

Luttinen, R.T. (2000). Level of service on Finnish two-lane highways. *Fourth International Symposium on Highway Capacity*, Maui, Hawaii, June-July 2000 175–187.

Luttinen, R.T. (2001). Capacity and level of service on Finnish two-lane highways. *Finnra Reports 18/2001*, Finnish Road Administration, Traffic and Road Engineering*,* Helsinki.

Luttinen, R.T. (2001). Traffic flow on two-lane highways - an overview. *TL Research Report 1/2001*, TL Consulting Engineers, Ltd., Lahti.

Luttinen, R.T. (2001). Percent-time-spent-following as a performance measure for two-lane highways, *Transportation Research Record,* No. 1776, Transportation Research Board, National Research Council, Washington, D.C., 52–59.

MORT&H (2012). *Basic road statistics of India 2008-09, 2009-10 & 2010-11*. Government of India, Ministry of Road Transport and Highways, Transport Research Wing, New Delhi.

Wang, C. and Morrall, J.F. (1987). *Two-lane highway level of service and simulation: Executive Summary Prepared for Alberta Transportation*. Alberta Transportation and Utilities. Research and Development.

Morral, J., & Werner, A. (1988). Measuring Level of Service of Two-Lane Highways by Overtakings. *Transportation Research Record,* No. 1287, Transportation Research Board, National Research Council, Washington, D.C., 62-69.

Polus, A., & Cohen, M. (2009). Theoretical and empirical relationships for the quality of flow and for a new level of service on two-lane highways. *Journal of Transportation Engineering*, ASCE, 135(6), 380 -385.

Roess, R., & McShane, W. (1987). Changing concepts of level of service in the 1985 highway capacity manual: some examples. *ITE Journal*, 27–31.

Romana, M, G., & Perez, I. (2006). Measures of effectiveness for level-of-service assessment of two-lane roads -an alternative proposal using a threshold speed. *Transportation Research Record*, No. 1988, Transportation Research Board of the National Academies, Washington, D.C.

Shawky, M., & Hashim, I. (2010). Impact of horizontal alignment on traffic Performance at rural two-lane highways. *4th International Symposium on Highway Geometric Design*, Valencia, Spain, June 2010.

TRB, (1985). *Highway Capacity Manual. (Special Report 209).* Transportation Research Board, National Research Council, Washington, D.C..

TRB, (2000). *Highway Capacity Manual.* Transportation Research Board, National Research Council, Washington, D.C.

TRB, (2010). *Highway Capacity Manual.* Fifth Edition, Transportation Research Board of National Academics, Washington, D.C.

Van As, S.C., & Van Niekerk, A. (2004). The operational analysis of two-lane rural highways. *23rd Southern African Transport Conference (SATC 2004)*, Pretoria, South Africa, July 2004.