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Assessment of level of service Measures for Two - Lane Intercity Highways under Heterogeneous Traffic Conditions

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ABSTRACT

Many researchers have studied the performance of two-lane intercity highways with the help of different measures. In the current study, the performance of such highways under heterogeneous traffic condition was examined by using several speed and followers related measures. The data were collected from five study sites located in different regions of India. A new methodology was proposed where followers were identified by using a Speed Difference (SD) (between two consecutive vehicles) range of -4 to +10 km/hr and gap threshold value (lower than a particular gap value) of 10 sec. By using acceptance curve method, different critical gap values were suggested for each site to identify the followers. Out of all the performance measures, the number of followers as a proportion of capacity (NFPC) and follower density (FD) were found to be the best and second best parameters. Finally, different LOS ranges were proposed based on NFPC using cluster analysis.

Keywords: Follower, Speed Difference, Gap Threshold, Headway Threshold, Level of Service

Introduction

Two-lane highways play a major role in the transportation system of India as well as other countries. According to the latest ministry report (MoRT&H, 2014-2015), two-lane highways constitute 53 percent of the total road length of National Highways (NH) in India. These highways which run between two cities are characterized by higher speed and low traffic volume in comparison to other highways. They have two lanes for two-directional traffic movements, i.e., one lane is provided for the movement of traffic in each direction. Fast moving vehicles pass slow moving vehicles after moving into the adjacent lane when the opportunity arises to do so and again come back to the original lane after completing the passing maneuver. A passing maneuver is possible only in the presence of a suitable gap between two consecutive vehicles and the safe overtaking sight distance. The interaction between vehicles increases with the increase in traffic volume and they are forced to maintain smaller gaps. It has serious implications on traffic operations and safety along two-lane intercity highways. This impact increases continuously due to the presence of slow moving vehicles and inadequate passing opportunity. These conditions result in a frequent platoon formation where many vehicles travel under the following condition and exhibit a poor level of service (LOS). LOS is very important for evaluating the performance of a particular highway facility, which helps in the decisions related to planning, design, maintenance and rehabilitation of it. A judgement on the proper utilisation of public funds can be made by assessing LOS of a particular highway facility. As speed related measures are easy to estimate from the field, several such parameters were used by different researchers in different countries to evaluate the performance of two-lane highways namely; average travel speed (ATS), average travel speed as a percentage of free-flow speed (ATS /FFS) (Al-Kaisy and Karjala 2008; Hashim and Abdel-Wahed 2011; Luttinen 2001b; TRB 2010), average

travel speed of passenger car (ATS_{PC}), ATS_{PC} as a percentage of free-flow speed of passenger car (ATS_{PC} / FFS_{PC}) (Al-Kaisy and Karjala 2008; Hashim and Abdel-Wahed 2011). A platoon or formation of the queue behind a slow moving vehicle (leader) is considered as an important aspect of defining traffic performance on two-lane highways. So, it is necessary to identify that which vehicles are the part of the platoon or not means which vehicles are travelling in the following condition and which are travelling in free flow condition. The frequent occurrence of platoon affects the performance of two-lane highways. Consequently, researchers across the world have used several follower-related parameters to evaluate the performance of two-lane highways which were found suitable for their traffic conditions. The most commonly used ones are percent time spent following (PTSF) and its surrogate measure percent followers (PF) (Luttinen, 2001a; TRB 2010), follower density (FD) (Al-Kaisy and Karjala 2008; Van As 2003; Catbagan and Nakamura 2006; Hashim and Abdel-Wahed 2011; Karjala 2008; Moreno et al. 2014; Munehiro et al. 2012; Oregon 2010; Shawky and Hashim 2010), and percent vehicles impeded (PI) (Al-Kaisy and Freedman, 2010). In most of these studies, followers were identified by using the 3-sec headway rule as suggested by the U.S. Highway Capacity Manual (TRB 2010). According to this definition, followers are those vehicles which travel behind slow moving vehicles with headway value equal to or less than 3 seconds. Few studies (Van As 2003 and Indonesian HCM 1997) found this headway value to be varying between 3.5 and 5 seconds. Penmetsa et al. (2015) used gap instead of headway to define followers (2.6 seconds) on two-lane intercity highways under heterogeneous traffic condition as several types of vehicles having varying length use the same facility. Though it was observed that they did not take into account the effect of traffic demand on this gap value. This study developed a new parameter, the number of followers as a proportion of capacity (NFPC), for studying the performance of two-lane intercity highways and proposed different threshold ranges of LOS. But, those LOS ranges were developed by using the PTSF

value provided in the U.S. HCM 2010 which is based on homogeneous traffic condition prevalent in the developed countries.

In India, a developing country, no standard talks about the LOS of two-lane intercity highways. In the absence of such guidelines, planners, and engineers in India are using the same methodology as suggested in U.S. HCM (2010). However, the traffic condition is totally different in India (heterogeneous in nature) comparatively developed countries. This traffic condition is characterized by diverse vehicle categories, changing composition, lack of lane discipline, etc. Because of that, it becomes problematic to use the same methodology under the heterogeneous traffic condition which can mislead the final results. Therefore, it is necessary to examine the relevance of these performance measures for Indian two-lane intercity highways under highly mixed traffic. The present study aims to identify the different ranges of LOS in order to evaluate the performance of the two-lane intercity highways under heterogeneous traffic condition.

Data Collection and Extraction

In order to examine the performance of two-lane intercity highways under highly heterogeneous traffic condition, five two-lane intercity highway sites are selected from different parts of India. Site 1 (NH-47) and Site 2 (NH-58) are located in the Southern and Northern part of India respectively, while Site 3 (NH-4), Site 4 (SH-31) and Site 5 (SH-59) are

in the Western and Northern India respectively. The chosen sites have a reasonably good surface condition with the same design speed of 80 km/h and geometric specification. These sites are located on straight sections with level terrain having 7.0 meter carriageway and 1.5 meter shoulder width. There is no influence of access points, intersections, and traffic control

devices up to 500 m in both directions. These rural highways do not have a distinct peak and off-peak hours and therefore data at all the sites are collected for 2 to 3 hours between 8 a.m. and 6 p.m. on typical weekdays using videography technique. At each of the sites, a longitudinal trap of 50 - 60 meter length was made on the road surface for the measurement of speed as shown in Fig. 1 (taken at Site 3 on NH – 4). The video camera was positioned in such a manner that each vehicle can be easily recognised along the entire length of the trap. Data extraction was carried out manually in the Civil Engineering laboratory on a large television screen. The location of the sites along with the duration of time for which data is extracted provided in Table 1. Consequently, traffic volume, vehicular composition, vehicular speed (average travel speed, 85th percentile speed) and headway value between two consecutive vehicles traveling in each direction are extracted from the collected video data. Vehicles are categorized into four categories, namely, passenger car (PC), motorized two-wheeler (2W), auto-rickshaw (AR) and heavy vehicle (HV) as shown in Table 1. The traffic volume is found to vary from 598 veh/h (Site 5) to 2789 veh/h (Site 1). Table 1 indicates that the highest proportions of PC and HV are observed on NH 4 while 2W's proportion is highest on SH-31. For NH-58 and SH-59, the proportions of PC and 2W are not varying much. Across all the sites, the percentage of PC is found to be between 15 and 46 percent whereas 2W composition varies from 21 to 73 percent.

Fig. 1.

A total of 16,640 vehicles were observed at all the study sites during the data extraction process. Information about the location of study sites, traffic composition, the total number of vehicles and vehicular volume counts are shown in Table 1.

Table 1

Methodology

All the variables (NFPC, FD, NF, PF, etc.) extracted from field video were arranged into 5-minute interval and later converted into the hourly unit. In order to take care of the effect of heterogeneous traffic condition, the PCU factor for each vehicle category was estimated using Equation 1 which was developed by Chandra and Kumar (2003).

$$[1] \quad PCU_i = \frac{\left(\frac{V_c}{V_i}\right)}{\left(\frac{A_c}{A_i}\right)}$$

Where,

V_c = speed of passenger car (m/s)

V_i = speed of vehicle type i (m/s)

A_c = Projected rectangular area of passenger car (m^2)

A_i = Projected rectangular area of vehicle type i (m^2)

Initially, all the most commonly used parameters in the previous studies like ATS, ATS_{PC} , ATS /FFS, etc., are examined in the present study. A new guideline is proposed in the present study to identify the follower and non-follower under heterogeneous traffic condition in order to use FFS and other follower related measures. A general problem often faced by various researchers in different research fields across the world is to organize the observed data sets in to a meaningful structure for developing the classifications. In order to provide different LOS ranges, clustering analysis technique is used in the present study. Cluster analysis is a procedure used to make different groups of similar types of data sets which actually incorporates different classification algorithms. Earlier, Jain et al. (1999) reviewed different clustering techniques and identified the clustering technique as a useful tool for different scientific studies. According to this study, Cluster Analysis can be defined as “a process of grouping the different data sets based on similarity”. Different type of distances, namely, Euclidean distance, Square-Euclidean distance and Cityblock distance are used in the clustering analysis process (Jain and Dubes, 1988). Earlier, Singh et al. (2013) examined the

suitability of different distance metrics for K-means clustering technique and it was concluded that the selection of distance metric plays an important role in the clustering analysis. Consequently, in the present study, two techniques named as Kappa statistics and Silhouette plot are used for the selection of the best distance metric. Cohen Kappa measures the agreement between two raters who classify the N objects into X exclusive categories. After validating the results different LOS ranges are proposed and a comparison is also made with the U.S. HCM 2010 proposed LOS ranges to distinguish the difference in both.

Analysis and Results

To define LOS of a transportation facility, a performance measure should be obtained such that it can be measured easily in the field and understandable to everyone (Ghosh et al. 2013). Consequently, nine parameters were used in the present study namely; ATS, ATS_{PC} , ATS_{FFS} , ATS_{PC}/FFS_{PC} , NFPC, FD, PF, NF, and DOB. To identify best the parameter to define LOS, few researchers (Al-Kaisy and Karjala 2008; Hashim and Abdel-Wahed 2011) studied several platooning related variables namely; traffic in the direction of travel, opposite traffic flow, the percentage of the passing zones and percentage of heavy vehicles. In order to evaluate the association of the above-mentioned performance measures with platooning phenomena on two-lane intercity highways, the relationships between these measures and two-way traffic volume (PCU/h) were examined. Among various platooning variables, passing zones are irrelevant as they are not provided on Indian two-lane intercity highways. In addition to this, none of the remaining platooning variables used by earlier studies were found to be associated with the selected measures. Because of that, a combination of traffic flow in the direction of travel and opposite direction, i.e., two-way traffic volume was used in the current study as a platooning variable. Besides this, in the current study gap was used instead of headway as analyses using headway were found inappropriate for the heterogeneous traffic condition due to its dependence on the vehicular length.

Assessment of the Performance Measures

All the parameters used in the study to examine the performance of two-lane intercity highways were categorised into two categories- speed related and follower related. Initially, all of the speed related measures are examined. Afterwards, various follower related parameters were examined.

Speed Related Measures

ATS of the traffic stream and ATS_{PC} were calculated by dividing the roadway length with the vehicular travel time required to traverse that particular road length. ATS and ATS_{PC} were easy to measure in the field and can be considered as good performance measures. Accordingly, different graphs were plotted for ATS and ATS_{PC} with traffic volume at all the study sites as exhibited in Fig. 2. ATS of the stream and passenger cars were found decreased with the increase in volume at all the study sites as shown in Fig. 2 (a) and (b) respectively. Out of five study sites, four were showing some relationship up to some extent while SH-31 did not show any trend. Along with this, very low values of the coefficient of the correlation (R^2) were observed at all the study sites. Table 2 provides the highest R^2 value observed for the relationship between ATS and ATS_{PC} among all the sites. In the previous studies (Al-Kaisy and Karjala 2008; Hashim 2011; Penmetsa et al. 2015), it has been concluded that the ATS and ATS_{PC} cannot be used as performance measures due to its dependence on the traffic volume and composition of vehicles. However, in the present study, relationships between ATS and traffic volume as well as ATS_{PC} and traffic volume were examined. But, ATS and ATS_{PC} did not show any correlation with the traffic volume as reported in the previous studies. Based on these observations, it was concluded that ATS and ATS_{PC} could not be used as performance measures for two-lane intercity highways under heterogeneous traffic condition. To examine the remaining speed related parameters, namely, PFFS (ATS/FFS) and

ATS_{PC}/FFS_{PC} which are the ratio of average travel speed and the free flow speed of all vehicles in the traffic stream and passenger car respectively, there is a need to calculate FFS for the heterogeneous condition. It is well known that a driver can travel at his/her desired speed when the vehicle travels under free flow condition (FFC). In earlier studies (Al-Kaisy and Durbin 2011; Hashim 2011), a critical headway value varying from 5 to 7 seconds was identified beyond which vehicles would be in FFC. Another study conducted by Fitzpatrick et al. 2003 calculated FFS by considering the vehicles which were travelling with 5 sec headway and 3 sec tailway. It is to note that while headway refers to the time difference between the front of a subject vehicle to the front of the leading vehicle travelling in same lane and direction of travel, tailway represents the time difference between the front of a subject vehicle to the front of the trailing vehicle travelling under the same condition.

Fig. 2.

In order to identify FFS and define FFC for heterogeneous traffic condition, initially, the previous methodologies as proposed by (Al-Kaisy and Durbin 2011; Hashim 2011) were used to establish the relationships of ATS and 85th percentile speed with headway threshold value (equal to or greater than a specific headway value i.e. 1, 2, 3..... so on). Fig. 3 (a) and (b) show these relationships for the NH – 47 study site. Unlike the previous studies, with the increase in headway threshold values, speed values (ATS and 85th percentile speed) do not become constant after a certain headway threshold value. Therefore, it was concluded that the headway cannot be used to identify the FFS as well as followers/non-followers under heterogeneous traffic condition. The same trend was observed at all the study sites.

Fig. 3.

Same relationships were established for ATS and 85th percentile speed with gap threshold value (equal to or greater than a specific gap value i.e. 1, 2, 3so on) among all the study sites as. Fig. 4 shows these relationships for NH – 47 site. As observed in Fig. 4 (a) and 4(b), ATS or 85th percentile speed does not become constant after any specific gap value. The same trend was observed among all the remaining study sites.

Fig. 4.

Thus, by carrying out different graphical analyses, it was concluded that the previously used speed related measures are not suitable to define FFS or differentiate between followers and non-followers for heterogeneous traffic condition. Consequently, in the present study, attempts have been to utilize speed difference (SD) and gap instead of previously used speed related measures (ATS and 85th percentile speed) and headway to identify FFC as well as the followers/non-followers. Initially, free moving vehicles were identified with the help of the new measure, namely, speed difference (SD), which is basically the difference in speed of two consecutive vehicles travelling in the same lane and direction and a gap threshold value (lower than a specific gap value i.e. 1, 2, 3,....so on) at all the study sites as shown in Fig. 5. A gap threshold value of 10 sec was observed at all of the study sites beyond which SD became almost constant, i.e., vehicles were found to travel at their desired speed under free flow condition (FFC). Consequently, FFS in this study was calculated from the 85th percentile speed of those vehicles which were travelling with a gap value more than 10 seconds.

Fig. 5.

Once FFS values were calculated for all the study sites, graphs were plotted for PFFS (ATS/FFS) and ATS_{PC}/FFS_{PC} with traffic volume as shown in Fig. 2 (c) and (d). In the current study, though PFFS (ATS/FFS) and ATS_{PC}/FFS_{PC} address the reference point issue (which was not the case with ATS and ATS_{PC}), these measures did not exhibit a good

relationship with traffic volume having a very low R^2 value. Table 2 summarizes the criteria for rejecting PFFS and $ATSPC/FFSPC$ as performance measures in the current study. Overall, based on the findings, it was concluded that none of the speed related measures could be used for the present study.

Table 2

Follower Related Measures

Different followers related measures were examined to identify the different ranges of LOS under heterogeneous traffic condition on two-lane intercity roads. In the previous studies, followers were identified by taking 3 sec headway rule as suggested in the U.S HCM 2010. In the present study, the followers were identified with the help of speed difference (SD) between two consecutive vehicles and the gap threshold at all the study sites as shown in Fig 5 above. It was observed that after a critical gap value of 10 sec vehicles would travel in FFC. Still, there was some confusion regarding vehicle movement in FFC below 10 sec critical gap threshold value. In order to identify follower and non-follower below 10 sec gap threshold value, a normal curve of free moving vehicles having a gap value greater than 10 sec was superimposed on the histogram of the SD of two consecutive vehicles in the traffic stream as shown in Fig. 6 (a) for one of the study site NH-47. The two points where the normal curve intersected the SD histogram (-2.20 and + 7.42 km/h) were used to classify vehicles as follower and non-follower. Similar graphs were plotted at the remaining sites also. Different SD limits ranges were observed across all the study sites as exhibited in Table 3. The minimum SD range value of -3.4 km/hr and maximum +10 km/hr was observed in the field among all the study sites. After a close examination of the data at all study sites, a SD limit range of -4.0 km/hr to +10 km/hr seemed more appropriate to classify the vehicles as follower and non-follower. So, vehicles which were travelling within a SD limit of -4 to +10 km/h and a gap value lower than 10 sec were identified as followers. In a recent study

(Penmetsa et al., 2015), a SD limit of ± 2 km/hr was used in order to identify the followers which was solely based on the accuracy of the video recorder used for data collection.

Afterwards, acceptance curve method (Gattis and Low 1999; Khan et al. 2015) was used to calculate the critical gap value beyond which probability of not following (PNF) would be more. A critical gap value of 1.9 sec was observed at NH 47 as shown in Fig. 6 (b). Same graphs were plotted at all the study sites and different critical gap values were observed across the sites as shown in Table 3. The main reason for the differences among these gap values was variation in the traffic volume across all study sites.

Fig. 6.

Table 3

The study conducted by Penmetsa et al. (2015) proposed a single gap value of 2.6 sec to identify the followers on two-lane intercity highways under heterogeneous traffic condition. This single critical gap value was observed for all the study sites due to non-consideration of the effect of traffic volume on the gap value. While in another study (Van As 2003), a critical gap value of 3.5 seconds was reported beyond which PNF would be more. In the current study, a range of SD (-4 to +10 km/h) was identified on the basis of actual field condition which seems to be more reasonable. The main reason for the different gap values observed in the present study was the variation in traffic volume from one site to another. Followers were identified by considering SD limit (-4 to +10 km/h) and different critical gap values observed at each site. Later on, previously used follower related parameters were examined in the current study. DOB is the ratio of a total number of followers in a traffic stream and the total number of vehicles in a particular time interval at a particular roadway facility. After establishing the relationship between DOB and traffic volume, data were found to be more scattered with a low goodness of fit as evident from Fig. 7 (a). NF and PF were estimated as the number of followers and percentage of followers present in a traffic stream respectively at

each study sites and their graphs are plotted against the traffic volume as shown in Fig. 7 (b) & (c). Among these two, PF also did not show that much significant correlation with traffic volume as shown in Fig. 7 (c). Though NF did show a significant correlation with traffic volume ($R^2=0.87$), its use as a performance measure could lead to other issues. It was earlier reported (Penmetsa et al. 2015) that NF does not always reflect actual congestion condition and it can mislead the results due to the variation of NF from one site to another. Because of that, NF cannot be used alone as a sole performance measure to evaluate the performance of two-lane intercity roads. Thereafter, NF was combined with the capacity of a particular highway and this parameter is termed as NFPC in order to explain the congested condition in a lucid manner. Therefore, NFPC is defined as the ratio of the number of followers and the capacity of a particular roadway facilities. It was observed that NFPC exhibited a good correlation ($R^2=0.86$) with traffic volume as shown in Fig 7(e). FD, the number of follower over a unit length, is also determined by using Eq. [2] and [3].

$$[2] \quad \text{Density } (D) = \frac{\text{Flow Rate (PCU/h)}}{\text{ATS}}$$

$$[3] \quad \text{Follower density (FD)} = \text{Density} \times \text{Percent followers}$$

When FD is plotted against traffic volume, it exhibited the 2nd best correlation with traffic volume ($R^2=0.82$) after NFPC. Consequently, NFPC and FD were used for further analyses as shown in Fig 7(f).

Fig. 7.

Assessment of Level of Service (LOS)

The main objective of the current study was to define different LOS ranges on the basis of field data. As it is a classification related problem, clustering analysis techniques were used to define different LOS ranges. Clustering analysis is a technique used to divide different data set or objects into classes of similar data or objects (Kouser and Sunita, 2013). By taking into account both NFPC and FD (the 1st and 2nd best parameters with respect to their correlation

with traffic volume), clustering analysis was carried out with the help of different distances, namely, Euclidean distance, Squared-Euclidean and City-block distance to develop different LOS ranges considering all the study sites. After carrying out the descriptive analysis of NFPC and FD, both data were found to be positively skewed as shown in Table 4.

Table 4

Consequently, k-median clustering analysis used instead of k-mean clustering. Five number of clusters were chosen in order to calculate six well-known LOS ranges as suggested by U.S. HCM (TRB, 2010). Data sets were grouped into five clusters with the help of certain specific distance measurements as mentioned earlier. The analysis was conducted in MATLAB and number of iteration was set to 100 in order to obtain optimal boundaries among the LOS. The results obtained from clustering analysis were evaluated with the help of Kappa statistics in order to find out the best algorithm for the field data set. Earlier studies (Brenner and Kliebsch 1996; Saha 2013) concluded that linear weighted kappa is less sensitive to the number of categories; because of that quadratic weighted kappa statistics was used in the present study to identify the best distance for clustering analysis. Squared-Euclidean and Cityblock distance was found suitable in the current study because of the highest agreement score as shown in Table 5. The kappa coefficient can be interpreted by using universal thumb rule as shown in Table 6.

Table 5

Table 6

Distance selection criteria for clustering analysis were validated with the help of the silhouette plot (Rousseeuw 1987; Saha 2013) in order to strengthen the results of the study as shown in Fig. 8. The significance of silhouette plot can be examined with the help of thickness and width of the silhouette plot curve for each level of service. A large width of the

silhouette for each cluster exhibits that strength of a particular cluster while thickness shows the number of data or objects in that particular cluster. Interpretation of silhouette value can be done with the help of universal thumb rule shown in Table 7. After examining the silhouette plots, an average value of silhouette 0.80 was obtained in the case of Squared-Euclidean distance which seemed reasonable. Different ranges of FD were calculated with the help of K-median clustering analysis for each cluster while different LOS ranges of NFPC were calculated from Eq. [4] which is the mathematical representation of the relationship between NFPC and FD.

$$[4] \quad FD = 73.29(NFPC)^{1.009}$$

The relationship between NFPC and FD was found statistically significant at 95% confidence interval with 0.9889 R^2 value. Different LOS ranges developed in the current study on the basis of this relationship are shown in Table 8.

Fig. 8.

Table 7

Table 8

As per U.S. HCM 2010 guidelines, LOS A describes the state when 35% of the vehicles in the traffic stream would be in the following condition. This value seems to be quite high as it contradicts the definition of LOS A (vehicles at this level travel at their desired speeds), especially for heterogeneous traffic condition. LOS ranges obtained in the current study seem more appropriate which are found to be lower than the ranges proposed by both U.S HCM 2010 and Penmetsa et al. (2015) as observed in Table 8. It has already been observed from the previous studies that the HCM 2010 overestimated the PTSF value in comparison to the field value. It is well known that the estimation of PTSF is very difficult in the field, especially under heterogeneous traffic condition. Consequently, a surrogate measure known

as PF had been used in previous studies as well as present study. But, in the present study, PF did not show good correlation with traffic volume as exhibited by FD and NFPC. Use of NFPC could be one of the reasons for obtaining lower LOS ranges with respect to the U.S. HCM 2010 proposed LOS ranges. Another reason could be pertinent to the use of SD and gap instead of ATS and headway value to define the followers and non-followers. The ranges suggested in the present study are found up to 9% lower than LOS ranges proposed by Penmetta et al. (2015). The main reason is that Penmetta et al. (2015) proposed the LOS ranges in terms of NFPC by using the U.S. HCM (TRB 2010) suggested PTSF values. Additionally, LOS ranges defined by Penmetta et al. (2015) is based upon the relationship obtained between PTSF and NFPC, whereas the present study proposes LOS ranges based on the relationship between FD and NFPC as PTSF is not found to be a significant measure under heterogeneous traffic. Moreover, the present study takes into account the effects of two-way traffic volume to identify a critical gap for defining followers while in the previous studies effect of traffic volume was assumed to be negligible.

Discussion and Conclusion

The performance of two lane highways is greatly linked to the presence of the followers which ultimately affects the LOS of a particular highway. Followers are defined as those vehicles whose movements get impeded due to the presence of slow moving vehicles ahead in the same traffic stream. Due to the inability to pass, vehicles are forced to travel in the following condition behind a slow moving vehicle, which leads to the formation of platoons. Historically, researchers across the world have used different follower related parameters in the previous studies in order to evaluate the performance measures for two-lane highways in terms of LOS. Most of these studies were based upon the 3-sec headway threshold rule as suggested in the U.S. HCM 2010. In India, a recent study Penmetta et al. (2015) suggested a

critical gap value of 2.6 sec to identify the followers for different study sites, but its limitation is that it did not consider the effect of traffic volume on the critical gap value. Another limitation of this study is that the same value of PTSF was used as suggested by U.S HCM 2010, to describe different LOS ranges for two lane highways under heterogeneous traffic. Therefore it cannot be used as a standard guideline to identify the followers under heterogeneous traffic conditions. In the absence of any such standards, researchers in India are using the U.S. HCM 2010 definition of followers. Under the heterogeneous traffic condition, different vehicle categories use the same transportation facility having different vehicular characteristics. The 3-sec headway rule, which is developed under relatively homogeneous traffic condition, is inappropriate to use under such conditions. Therefore, an attempt is made to develop a new methodology which can be utilized for identifying the followers on two-lane intercity highways under heterogeneous traffic condition.

Five different sites along two-lane intercity highways, located in different parts of India are selected. Different relationships are established between SD and gap threshold values after making several trials to identify non-followers so that a critical gap value can be identified at or beyond which vehicles can be defined as in the following or non-following condition. For all the sites, a gap threshold value of 10 sec is observed beyond which vehicles will not be in the following condition. In another word, the presence of the slow leading vehicles will not influence the movement of the following vehicles and vehicles can travel at their desired speed. Still, there is a possibility that some vehicles travel in non-following condition with a gap value less than 10 sec. So, a number of trials are made to define a range of Speed Differences (SD) between two consecutive vehicles and identify the followers and non-followers traveling on two-lane highways. A SD limit is identified after superimposing the normal distribution curve of the SD for free flowing vehicles (i.e., vehicles those are travelling with gap value greater 10 sec) on the histogram of SD for all vehicles. After a close

examination of the all the histogram and normal curve plots for all the study sites, a SD limit of -4 to +10 km/hr is identified which can describe the following vehicles (or followers) only when they travel within this limit. Vehicles traveling beyond this range of SD are identified as “non-followers” . Thereafter, cumulative distribution curves for non-following vehicles and corresponding gap values between two consecutive vehicles are plotted. Gap values corresponding to 0.5 probability of the cumulative distribution of non-following vehicles (or 50 percent chance) are estimated. These critical gap values are observed to be ranging from 1.9 sec to 4.3 sec for different sites. The main reason for the variation in the gap value is found to be the variation in the two-way traffic volume. Followers can be identified at different study sites with the help of equation developed from non-linear model of the relationship between the gap and two-way traffic volume. After that, the association between different follower related measures and two-way traffic volume are examined and among all of the measures NFPC is found most suitable measure as it shows the strong correlation with two-way traffic volume followed by FD. A cluster analysis technique is used to define different threshold ranges of LOS. Different ranges of LOS are proposed in the present study by using the relationship between NFPC and FD. The LOS ranges presented in this study are found lower than the LOS ranges given in the HCM (TRB 2010) and the one proposed by Penmetsa et al. (2015). The present study identifies traffic volume as the main factor affecting the followers and thus performance of two-lane intercity highways, whereas past studies did not account for traffic demand. The follower identification guidelines presented in this study can be effectively utilized in determining the different level of service (LOS) ranges for two-lane highways of developing countries under heterogeneous traffic conditions. The proposed methodology will help the traffic engineers and planners to design the highway facility under heterogeneous traffic conditions. The collection of additional data from

different road sections having variation in traffic volume and composition can be considered for future research.

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Abbreviations used in the Study

ATS	= Average travel speed
ATS _{PC}	= Average travel speed of passenger car
PFFS (ATS/FFS)	= Average travel speed as a percentage of free-flow speed
ATS _{PC} / FFS _{PC}	= average travel speed of passenger car as a percentage of free-flow speed of passenger car
SD	= Speed Difference
FFS	= Free flow speed
FFC	= Free flow condition
FD	= Follower density
PF	= Percent follower
NF	= Number of followers
NFPC	= Number of followers as a proportion of capacity
DOB	= Degree of Bunching
PTSF	= Percent time spent following

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Table 1. Vehicle Composition with Traffic Flow for Each Site

Site	Chainage	Time	Total vehicles	PC (%)	2W (%)	AR (%)	HV (%)	Volume (veh/hr)
NH 47	98 km	10 a.m – 1 p.m	8367	33.62	45.67	14.00	6.71	2789
NH 58	23 km	4 p.m - 6 p.m	3547	39.05	41.33	9.75	9.87	1773
NH 4	55 km	10 a.m - 12 a.m	1892	46.46	21.40	7.09	25.05	946
SH 31	5 km	11 a.m – 1 p.m	1637	15.10	73.05	5.15	6.70	818
SH 59	22 km	11 a.m – 1 p.m	1197	39.36	38.67	6.54	15.43	598

Table 2. Regression Analysis Results of the Performance Measures

Performance Measures	Site	Best Fit	R ² Value	Rejection Criteria
ATS	NH - 47	ATS = -0.0045 volume + 54.931	0.416	Lack of reference point with poor R ² value
ATS _{PC}	NH - 47	ATS _{PC} = -0.0065 volume + 61.903	0.366	Same as of ATS
PFFS	All	PFFS = 0.000001 volume ² - 0.0046 volume +73.175	0.088	R ² is low
ATS _{PC} /FFS _{PC}	All	ATS _{PC} /FFS _{PC} = -0.0087 volume + 84.90	0.360	R ² is low

Table 3. Gap values at different sites

Sites	Flow (veh/hr)	Gap (sec)	SD (km/h)
NH 47	2789	1.9	-2.20 to +7.42
NH 58	1773	3	-0.43 to +4.09
NH 4	946	3.4	-0.69 to +9
SH 31	818	3.7	-2.53 to +10
SH 59	598	4.3	-3.41 to +6.12

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Table 4. Descriptive Analysis of the NFPC and FD

Summary	NFPC	FD
Mean	0.208	15.01
Median	0.206	15.47
Skewness	0.56	0.53
Kurtosis	-0.54	-0.61
St. Deviation	0.160	11.88

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Table 5. Quadratic Weighted Cohen Kappa Expected Agreement Obtained by Partitional Clustering
Methods and Sum of Agreement Scores for Each Method

Cluster Methods Distance Measures		K-Median	K-Median	K-Median	$\sum$ Agmt. scr
		Euclidean	Squared	Cityblock	
			Euclidean		
K-Median	Euclidean	-	-0.1176 ⁽⁰⁾	-0.1176 ⁽⁰⁾	0
K-Median	Squared Euclidean	-0.1176 ⁽⁰⁾	-	1 ⁽⁴⁾	4
K-Median	Cityblock	-0.1176 ⁽⁰⁾	1 ⁽⁴⁾	-	4
$\sum$ Agmt. scr		0	4	4	

- Superscripts to the Kappa Coefficient indicates the agreement score

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Table 6. Interpretation of Kappa and Proposed Agreement Score

Kappa Coefficient	Strength of Agreement	Agreement Score
<0.20	Poor	0
0.21-0.40	Fair	1
0.41-0.60	Moderate	2
0.61-0.80	Good	3
0.81-1.0	Very Good	4

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Table 7. Validation Criteria of Cluster

Range of Average Silhouette Value	Interpretation
0.71-1.0	A strong structure has been found
0.51-0.70	A reasonable structure has been found
0.26-0.50	The structure is weak
<0.25	No substantial structure has been found

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Table 8: Proposed LOS Ranges Obtained from Partitional Data Clustering

LOS	PTSF (HCM, 2010)	NFPC (Penmetsa et.al.,2015)	Proposed NFPC
A	≤ 35	≤ 0.15	≤ 0.13
B	$>35-50$	$>0.15-0.31$	$>0.13-0.28$
C	$>50-65$	$>0.31-0.51$	$>0.28-0.39$
D	$>65-80$	$>0.51-0.75$	$>0.39-0.50$
E	>80	>0.75	$>0.50-0.66$

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List of Figure Captions

Fig. 1. Camera view at NH 4 site

Fig. 2. Variation in Speed related measures w.r.t Volume

Fig. 3. Variation in ATS and 85th percentile speed w.r.t headway value equal to or greater than a specific threshold value at NH – 47

Fig. 4. Variation in ATS and 85th percentile speed w.r.t gap value equal to or greater than a specific threshold value at NH – 47

Fig. 5. Variation in Speed Difference w.r.t Gap Threshold at all the Study Sites

Fig. 6. (a) Histogram of the speed difference between consecutive vehicles. Superimposed is the normal curve of relative speed of non-following vehicles (b) Probability of not following at NH- 47

Fig. 7. Variation of All Performance Measures

Fig. 8. Silhouette Plot by using (a) Square-euclidean Distance and (b) Cityblock Distance for NFPC and FD

(a)

(b)