Automobile Level of Service Criteria for Two-Lane Undivided Heterogeneous Urban Corridors

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Abstract

The macroscopic parameters considered in Highway Capacity Manual for defining the automobile Level of Service (LOS) seems inadequate to capture the variations in quality of travel perceived by the users in every moment (seconds). Hence the study reported here aimed to develop the LOS criteria for automobiles on undivided urban corridors considering the variations in microscopic parameters which influence the quality of the travel over a period of time or distance. Detailed speed profile data were collected second-to-second basis on the selected urban corridors in the state of Kerala, India using a GPS-based mobile application installed in the test vehicles. Two-wheelers, three-wheelers, and cars were considered separately due to the variations in their static and dynamic characteristics which influences their maneuverability and LOS experienced under a given traffic condition. The coefficient of variation of speed (CV) and congestion index (CI) was estimated using the speed profile observed and found to be more reliable measures to evaluate the LOS. Two step clustering technique was used for evolving the level of service criteria based on speed ratio, CV, and CI. Considerable variation is observed in the criterion values estimated for different vehicle types under the automobile category comparing with HCM 2010 values, and hence this new methodology can be used as a basis to assess the LOS from the individual drivers' point of view.

Keywords: Level of Service (LOS), Coefficient of Variation of speed (CV), Congestion Index (CI), and two-step clustering.

1. Introduction

Cities are the engines of economic activities of a country. India has been witnessing rapid urbanization for the last three decades, (31% of the population lives in urban areas) as per 2011 census. With the increase in urbanization and growth of personal motorized transport modal share, the performance of urban roads has become the major concern for the policy makers and planners. An appropriate methodology formulation has become the primary goal for the transportation professionals to understand the quality of travel perceived by the automobiles while traveling through the urban corridors, which is a combination of a number of midblock and intersections. HCM 2010 has proposed a multimodal level of service criteria for urban roads by considering macroscopic parameters of traffic flow. In the multimodal aspect, the travel quality of automobile, transit, bicycle and pedestrian are considering separately. Expressing the level of service based on the aggregate outcome of macroscopic parameters may not be appropriate to reflect the actual experience perceived by the user. Understanding the traffic flow inconsistency, mainly on the microscopic (individual driver/vehicle) level, is vital since the level of service should be assessed from the viewpoint of the roadway user.

HCM 2010 and IRC 86 (1983) guidelines given that level of service of the urban street is influenced by variables like nature of traffic, volume of pedestrians, number of intersections, bus stop location, road-side parking, on- street businesses etc. NCHRP 616 report (2008) and (Richard et al., 2008) presented the level of service in a multimodal perspective considering the urban street facilities. They developed a probabilistic level of service models for automobile, pedestrian, bicycle, and transit modes. These models allocate a classification of LOS from A–F based on the characteristics of the traffic, type of intersections, and road geometry. In the state of the art on Level of Service 2010 and beyond the additional measures to be added for the future multimodal LOS criteria were discussed in detail (Roger et al., 2010).

However, the automobile users giving more importance for the individual travel characteristics than the macroscopic traffic parameters and only a little amount of study has been conducted in this area. For example, the impact of acceleration noise to the travel quality on freeways was studied comprehensively by many researchers. For examining the driver response during the travel, acceleration noise has considered as a highly sensitive measure (Torres, 1970). Also, speed profile data is an effective variable for modeling the urban road congestion in heterogeneous traffic condition. The coefficient of variation of speed and quantified level of congestion can be used as the quality measures of the level of service (Nagaraj and Anjaneyulu, 2009). The microscopic parameters of freeway traffic flow were examined by (Oh et al., 2005), using some macroscopic techniques. They considered the traveling behavior of a freeway and calculated the Re-identified Median Section Speed. They recommended for modifying the existing travel quality measure, density by RMSS criteria obtained by using K-means clustering algorithm. Also, (Ko et al., 2006) explored the use of GPS mounted probe vehicles to collect the speed variation characteristics of traffic flow. They understood that the quality of travel perceived by different drivers is not similar under the same traffic condition.

The measures of LOS can be classified by using clustering techniques. For the classification of LOS of the signalized intersection (Cheol and Stephen, 2002) used the Self-Organizing Map (SOM), Fuzzy, and K-means clustering techniques and compared their validity. Again classification of highways by using the Kohonen neural network clustering algorithm and comparison of the result with the hierarchical agglomerative technique was done by (Lingras, 1995). He recommended that the Kohonen neural network and the hierarchical classification can be used for complete road networks and the least-mean-square technique can be used for classifying the incomplete road networks. Also, a level of service criteria for urban roads was defined by using Hierarchical Agglomerative Clustering technique (Bhuyan and Rao, 2011). New ranges of speed values have been introduced for all classes of urban roads for heterogeneous traffic condition which are different from HCM ranges. Thus the findings of the earlier studies which differs from HCM values especially under mixed traffic condition forms the motivation for the present study.

2. Methods of Measuring Quality of Service on Urban Corridors

The traditional way of evaluating urban road traffic flow quality of service has relied on the mean speed of a medium sized vehicle and its volume to capacity ratio. The earlier version of the HCM has suggested for deriving the level of service of urban streets based on average through vehicle travel speed for the roadway segment under consideration. The average travel speed can be estimated either from the direct field observations or from the urban street traffic flow models. The above approach may be appropriate as long as the traffic composition is homogeneous in nature and the relative difference between different modes are to a minimum level.

When the traffic stream of the urban road comprised with modes of widely varying operational characteristics, the level of service experienced by different mode users differ significantly due to the variation in their operational and maneuverability characteristics under a given traffic flow condition. Using the aggregate measure of the same level of service criteria values for different modes become against the real scenario. Therefore, the level of service criteria for different modes needs to be developed based on the traffic flow parameters observed continuously on the microscopic level.

Moreover, the average travel speed alone will not fully describe the traffic flow quality experienced by the drivers since two vehicles with identical mean speeds may have totally different speed profiles over their respective trips. When a vehicle travels on an urban road with very low traffic flow, the variations in speed will be minimum. As the traffic flow increases, vehicle interaction also increases and the average travel speed begins to fall with a greater amount of variations in speed profile. The velocity profile of the vehicle will become oscillatory when the driver tries to change the speed in response to the neighboring vehicles (Nagaraj, 2009). In order to understand the microscopic parameter which narrates the variation in speed exactly to the driver perception, various speed indices like velocity noise (VN), coefficient of variation (CV), acceleration noise (AN), and mean velocity gradient (MVG) of speed were studied in depth.

Velocity noise is the standard deviation of speed along the roadway. The velocity noise which describes the speed variations of the vehicle over the travel duration or distance indirectly reflects the level of effort needs to be put by the user to maintain that speed profile. Hence, it is an appropriate measure to quantify the quality of service received by the user. Velocity noise can be calculated by using the Eqn. (1)

$$VN = \sqrt{\frac{\sum_{i=1}^{N} (V_i - MS)^2}{N - 1}} \quad (1)$$

Where V_i is the speed of vehicle at i^{th} interval of time or distance

N is the total number of intervals in the trip

MS is the mean speed of the trip

Coefficient of variation of speed is the derived measure obtained as the ratio of standard deviation of speed to mean speed and can be mathematically expressed as in Eqn. (2)

$$CV = \frac{VN}{MS} \times 100 \quad (2)$$

Acceleration Noise is the standard deviation of acceleration along the roadway which can be calculated by using Eqn. (3). It will show the amount of variation in acceleration with the mean value while traveling in an urban corridor.

$$AN = \sqrt{\frac{\sum_{i=1}^{N} (A_i - MA)^2}{N - 2}} \tag{3}$$

Where A_i is the change in speed of the vehicle from i^{th} interval to $(i+1)^{th}$ interval

MA is the mean acceleration

Mean Velocity Gradient is the ratio of the acceleration noise to the mean speed which is given in Eqn. (4)

$$MVG = \frac{MA}{MS} \times 100 \tag{4}$$

In order to establish a meaningful relationship between the indices and the traffic stream variables, a detailed analysis was done with all the indices considering two wheelers, three wheelers, and cars separately. It was clearly observed from the analysis that the coefficient of variation of speed is having the highest correlation with flow values for all the modes and the change in trend was able to justify logically. At lower flow condition the value of the coefficient of variation is less since the driver has full freedom to maneuver, which means that variation in speed will be minimum (Sudheer Babu, 1995). When the flow increases the interaction with other vehicles will become more frequent and the drivers are forced to perform frequent speed changes in order to maintain the desired speed. Further increase in the flow near to capacity condition results in few opportunities for overtaking and there by the driver will be forced to follow other vehicles. All the vehicles will be following their front vehicles in an orderly manner without any over takings. Hence the variations in speed will be minimum (Nagaraj, 2009). This scenario is observed through the increasing and decreasing trend of CV over the volume of traffic. An added significant reason is that CV can also be used to calculate the vehicle emission and hence the fuel consumption and cost of travel within a specified speed variation characteristics.

The macroscopic parameters frequently used by the planners to express the quality of travel on urban roads are the speed ratio and the volume capacity ratio. State of art relating the level of service revealed the variations in magnitudes of quality parameters in homogeneous and heterogeneous traffic conditions (Bhuyan, 2011). So it is obvious to consider those parameters also for formulating the criteria. Therefore the speed ratio is found to be the second measure and congestion index (CI) became the third one. Congestion index provides the congestion levels in different stretches of road. It is the measure of the extra travel time taken by the user for finishing the travel when compared to the free flow travel time. A small value of congestion index represents the good quality of traffic flow (CI varies from 0.1 to 4.0 in the present study). Eqn. (5) gives the mathematical expression for CI.

$$Congestion\ \ Index = \frac{Actual\ \ travel\ \ time - Free\ \ flow\ travel\ \ time}{Free\ \ flow\ travel\ time} \tag{5}$$

Speed ratio is the ratio between mean travel speed to the mean free flow speed of that road. The free flow speed can be defined as the desired speed of the vehicle in low traffic flow conditions without the interference of other vehicles and in the absence of traffic control devices.The value of speed ratio is varying from zero and one and the higher speed ratio value indicates the best quality road. Speed ratio can be mathematically calculated as in Eqn. (6)

$$Speed\ Ratio = \frac{Mean\ \ speed\ \ of\ \ a\ \ trip}{Free\ \ \ flow\ \ speed} \qquad (6)$$

Operating traffic volume, the easily measurable characteristic of traffic flow is chosen as the influencing factor and the quantification of the level of service is done based on the observed relationship between the coefficient of variation, congestion index and speed ratio with operating volume. For urban roads with mixed traffic conditions, these unconventional parameters were never attempted to define the level of service criteria. Considering these facts, the level of service criteria for undivided two-lane urban corridors were developed here by using CV, CI, and Speed ratio.

3. Study Area and Data Collection

3.1 Study Area

The study stretches for the data collection were selected from Calicut and Thrissur in Kerala, India. Calicut city is situated on the west coast of India at a latitude of 11° 15' N and a longitude of 75°45' E. It is the third largest city in Kerala. The city of Thrissur is located in south-western India at a latitude of 10° 31' 12" N and a longitude of 76° 12' 36" E and it is the central part of Kerala. Three two-lane two-way urban corridors with un-signalized intersections having varying length of 3.6 km to 4 km were taken as the study stretches. The first one was from Pushpa junction to Meenchanda bypass junction and the second road stretch is from Nadakkavu junction to Puthiyagadi junction along the Kannur Road in Calicut. The third from Thrissur St.Thomas College junction to Anjerichira junction has considered for the study. Since the geometry, demand, and traffic flow characteristics are not uniform throughout the corridors, each corridor has divided into a number of segments which is a combination of a midblock and a preceding intersection having similar geometric characteristics. The first study corridor has divided into four segments and the second and third corridors have divided into three segments each for the analysis. The details of the segments are given in Table 1.

Table 1: Characteristics of the Study Segments in the Selected Corridors

Seg. No	*Road Width(m)*	*Segment length (km)*	*Max flow (PCU/hr)*	*Max flow (PCU/hr /m)*	*No. of approach Roads*	*Bus stops*	*Parking*	*Distance from intersection*	*Other features which affect speed*
1	10.9	1.1	3254	298.53	3	2	No parking	300 m	Bridge
2	11.8	0.9	3656	309.84	1	2	Both sides	200 m	Railway gate and station
3	10.8	1.1	3936	364.44	0	3	Both sides	450 m	School
4	8.3	0.9	3352	403.97	1	2	No parking	200 m	Arts college, Fire station
5	9.35	1.75	4236	453.05	4	4	Both sides	700 m	School
6	10.26	0.95	2682	261.4	3	2	Both sides	200 m	College
7	11.05	1.3	3234	292.67	4	4	Both sides	400 m	-
8	10.54	0.7	5022	476.47	4	2	No parking	150m	College, Hospital
9	10.77	1.4	4178	387.93	6	4	Both sides	325 m	School, Hospital
10	8.84	1.6	2305	260.77	6	2	Both sides	200 m	-

3.2 Data Collection

To develop the criteria for automobile level of service three types of data are collected. The first one was the road inventory data, to divide the corridor into segments. This was collected from records and measured from the site. The second was the mean speed data of free flow, peak, and off-peak flow conditions. Speed data were collected using a GPS-based mobile application and the data were recorded continuously for a time interval of one second. Data collected by this application includes both spatial and time/distance, which will help to determine various traffic parameters such as travel time and travel speeds (instantaneous and average). Altitude and location coordinates were also recorded by this application. The traffic characteristics which includes classified volume count and density was collected using video graphic technique. The peak and off-peak speed data were collected for around eight and a half hours during 06:00 AM to 11:00 AM and 02:30 PM to 06:00 PM along with traffic flow data for a period of three days. Mode wise speed data were collected for two-wheelers, three-wheelers and cars with 1 trip in each 15 minutes of the specified time period mentioned above. A Total of 942 trips were made by using all the three modes to collect the frequent traffic characteristics of the study corridors. Free flow speed data collected separately during early morning hours when the traffic flow was very less. Sample output obtained from the application is given in Table 2.

Table 2: Speed Profile Sample Output from the GPS Application

Date	*Time*	*Elapsed time*	*Distance (km)*	*Speed (km/h)*	*Latitude*	*Longitude*
31/12/15	3:03:00 am GMT+5:30	00:00	0	0.8	11.27245	75.77528
31/12/15	3:03:01 am GMT+5:30	00:01	0	1.5	11.27245	75.77528
31/12/15	3:03:02 am GMT+5:30	00:02	0	2	11.27247	75.77527
31/12/15	3:03:03 am GMT+5:30	00:03	0	3.3	11.27249	75.77527
31/12/15	3:03:04 am GMT+5:30	00:04	0.01	5.4	11.27251	75.77526
31/12/15	3:03:05 am GMT+5:30	00:05	0.01	7.6	11.27253	75.77526
31/12/15	3:03:06 am GMT+5:30	00:06	0.01	7.7	11.27254	75.77525
31/12/15	3:03:07 am GMT+5:30	00:07	0.01	7.7	11.27255	75.77525
31/12/15	3:03:08 am GMT+5:30	00:08	0.01	10.3	11.27259	75.77523
31/12/15	3:03:09 am GMT+5:30	00:09	0.02	18.4	11.27265	75.7752
31/12/15	3:03:10 am GMT+5:30	00:10	0.02	17	11.27268	75.77521
31/12/15	3:03:11 am GMT+5:30	00:11	0.03	18.5	11.27273	75.77518
31/12/15	3:03:12 am GMT+5:30	00:12	0.03	16.1	11.27275	75.77516
31/12/15	3:03:13 am GMT+5:30	00:13	0.04	16.5	11.27279	75.77515
31/12/15	3:03:14 am GMT+5:30	00:14	0.04	19.3	11.27284	75.77513
31/12/15	3:03:15 am GMT+5:30	00:15	0.05	19.6	11.27288	75.7751
31/12/15	3:03:16 am GMT+5:30	00:16	0.05	20.2	11.27293	75.77508
31/12/15	3:03:17 am GMT+5:30	00:17	0.06	22	11.27301	75.77508

Five minutes interval volume has calculated for each segment and converted to PCU/hr/m by using IRC 86-1983 guidelines. From the traffic composition it was found that in the heterogeneous urban traffic of developing cities, the two-wheeler takes the highest percentage following with car and three-wheeler. Figure 1 shows the typical traffic composition in selected urban corridors. It is understood that the majority of the traffic, around 88% is composed of two wheelers, three wheelers, and cars. Hence by considering these three categories of vehicles will become the representation of the automobile category in the multimodal LOS analysis.

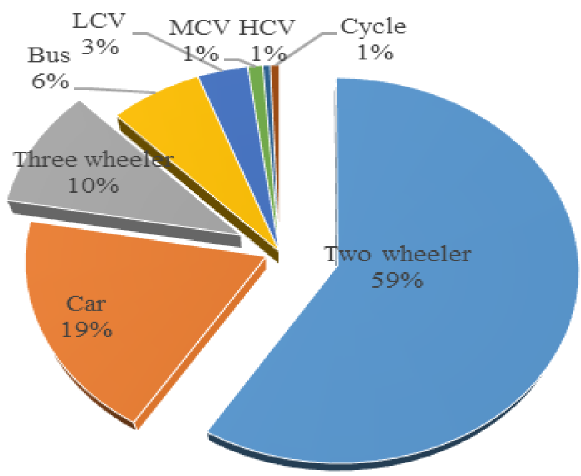
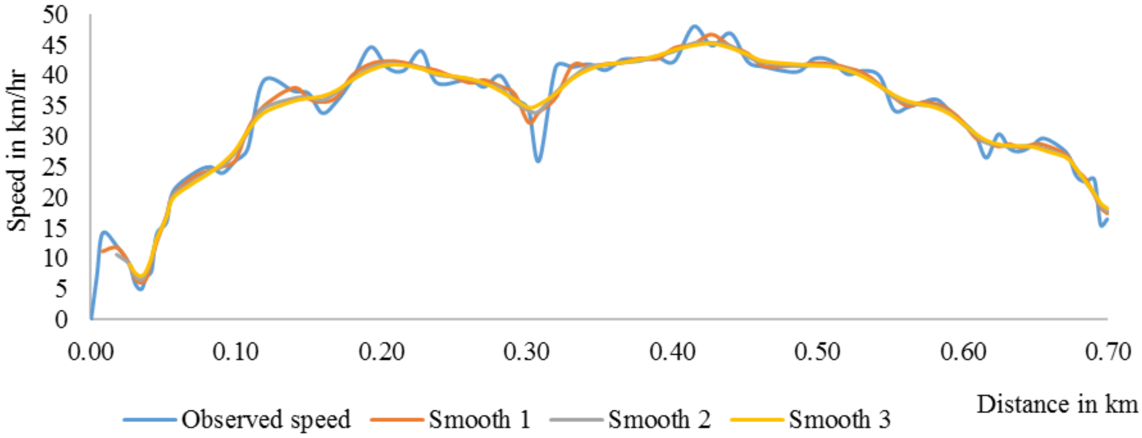
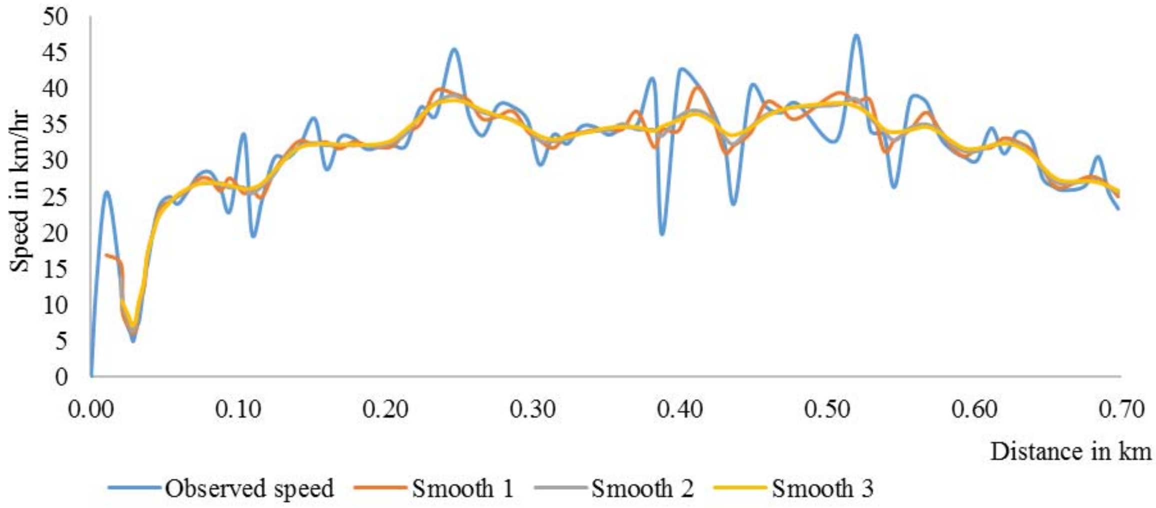


Figure 1: Traffic Composition in the Study Corridors

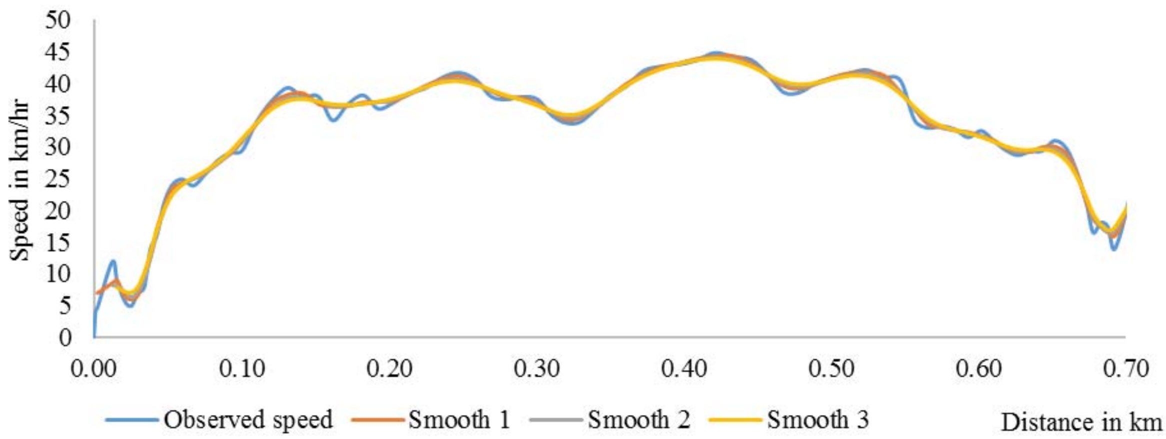
Speed profiles were plotted for all segments and for all the three modes two wheelers, three wheeler, and car separately. In order to remove the noises in the speed profile, the observed speed data was smoothened by using moving average method (3MA). The smoothened data is used for the further analysis. A comparison of speed profiles of a single segment with smoothened speed for all the three modes is shown in Figure 2. It is clear from the plot that two-wheelers and three-wheelers are having higher fluctuations in their speed compared to the car within the similar traffic condition. This is due to their smaller dimension and easily maneuvering capability in the available road width. The variations in the speed is also a reflection of the driver behavior on the urban roads. Since the speed profiles of each modes are entirely different within the same traffic, they have to be addressed individually in the analysis. The smoothened data provides a better understanding of the deviations of speed in the urban segments.



2a) Two Wheeler



2b) Three Wheeler



2c) Car

Figure 2: Smoothening of Speed Profile Data: Comparison of Different Modes

Figure 3 shows the comparison of the mean speed of the three modes within the same geometry and traffic flow conditions. In the two-lane undivided heterogeneous urban traffic, two wheeler is having the highest speed (52 km/hr), due to its smaller size and easily maneuvering capability. Three wheeler is having the lesser power compared to other modes and hence their speed is less (46 km/hr), in the low traffic volume (<75PCU/hr/m). But when the traffic volume increases, we can identify from the plot that the speed of the car reduces to the minimum value (21 km/hr), because of the lesser maneuverability compared with the three wheeler. In the mixed traffic, for the same flow condition, different vehicles are showing significant variations in speed characteristics. Hence it is clear from the graph that to capture the perception of automobile drivers it is necessary to consider the three modes i.e., two wheeler, three wheeler, and car which is predominant in the heterogeneous traffic composition, separately for the analysis.

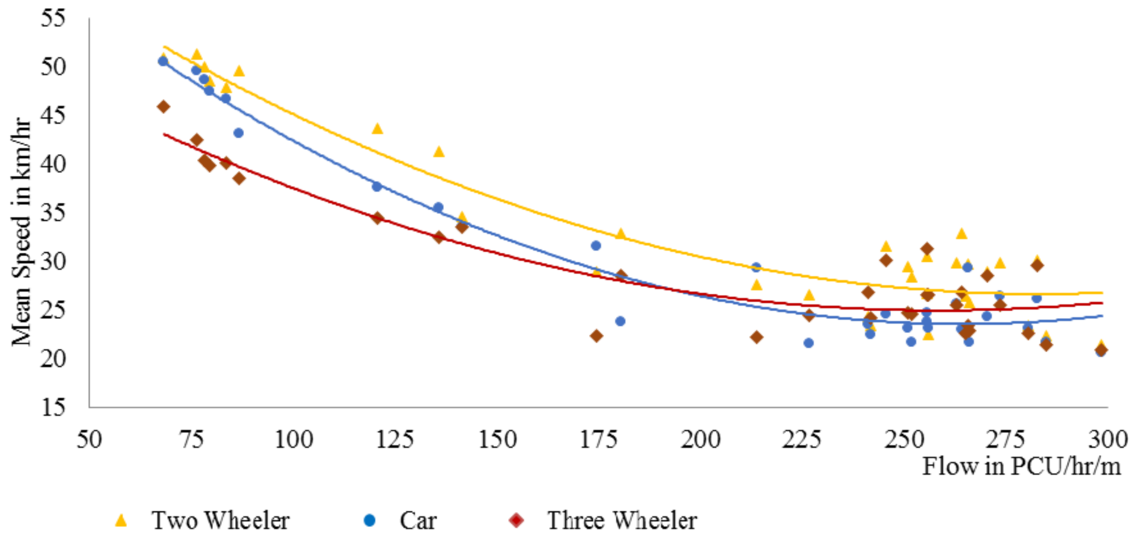


Figure 3: Mean Speed Comparison of Different Modes

4. Selection of the Microscopic Parameters for LOS Quantification

In the preliminary data analysis, all the speed indices were calculated for each segment and tabulated. A correlation matrix was formed for all the modes. The results from the Table 3 indicates that the Mean Speed (MS), Coefficient of Variation of speed (CV) and Congestion Index (CI) are highly correlated with flow rates, and hence selected for LOS criteria development. The coefficient of variation of speed seems more suitable parameter as it retains the fluctuations of speed profile and incorporates both speed and standard deviation of speed. It is seen from the analysis that CV increases with an increase in flow up to half the capacity and then it starts reducing to a particular limit with further increase in flow. This is because the traffic behavior is unpredictable until the flow reaches up to half of its capacity and after that, the drivers start losing the freedom of travel and hence the decreasing trend of CV. The road and driver effects were removed by deducting the $CV_{Freeflow}$ from the CV_{Total}. So the coefficient of variation due to the flow effect alone was calculated for the study. Since the flow did not reach its capacity during the data collection, standard Speed Flow curves were plotted and found the flow level at capacity. They are 520PCU/hr/m, 540PCU/hr/m and 545PCU/hr/m for two wheeler, three wheeler and car respectively. The corresponding CV values where calculated from the CV Flow curves and they were found to be 49.48, 40.48 and 60.77 for two wheeler, three wheeler and car respectively.

Table 3: Correlation Matrix for Different Modes

3 a) Two-wheeler

	Flow/m	*MS*	*VN*	*CV*	*AN*	*MVG*	*CI*
Flow/m	1						
MS	**-0.8350**	1					
VN	0.5566	-0.5618	1				
CV	**0.7552**	-0.8709	0.8371	1			
AN	0.4381	-0.5237	0.6025	0.6330	1		
MVG	0.6482	-0.7968	0.5729	0.8301	0.8749	1	
CI	**0.7250**	-0.8486	0.4635	0.7749	0.4284	0.7056	1

3 b) Three-wheeler

	Flow/m	*MS*	*VN*	*CV*	*AN*	*MVG*	*CI*
Flow/m	1						
MS	**-0.7561**	1					
VN	0.5257	-0.5194	1				
CV	**0.6928**	-0.8091	0.8721	1			
AN	0.4151	-0.3364	0.4979	0.4843	1		
MVG	**0.6694**	-0.7601	0.5732	0.7882	0.8205	1	
CI	**0.5465**	-0.7990	0.3977	0.7087	0.2408	0.6611	1

3 c) Car

	Flow/m	*MS*	*VN*	*CV*	*AN*	*MVG*	*CI*
Flow/m	1						
MS	**-0.8468**	1					
VN	0.5589	-0.6118	1				
CV	**0.7582**	-0.8602	0.8611	1			
AN	0.4172	-0.4667	0.4873	0.4859	1		
MVG	0.7005	-0.7989	0.5602	0.7827	0.8337	1	
CI	**0.7107**	-0.7353	0.4607	0.6953	0.3519	0.6575	1

Congestion is the undesired traffic volume effect on the urban roads resulting from the increased travel time to the users. Congestion index is one of the delay parameters which is showing a specific increase in trend with the flow. Depending on the free flow speed of a particular automobile congestion index starts from zero and reaching a higher value of four in the study stretches. These values were calculated for all the ten segments and combined analysis was done. From the detailed analysis, it is clearly understood that there are definite relationships exists between the traffic flow and the microscopic parameters such as coefficient of variation of speed (CV) and the congestion index (CI). While developing the criteria for the level of service using these parameters, appropriate range of these parameters need to be identified to represent those ranges corresponds to a level of service category. These microscopic parameters are continuous variables and can take any values between the minimum and maximum. Clustering is the best available method for grouping these continuous variables.

5. LOS Criteria Development Using Two-Step Clustering

Cluster analysis is a convenient method for classifying or grouping of a collection of objects into subsets or clusters, such that the members within a cluster are closely related compared to the other cluster members. The two- step clustering was introduced by Chiu et al (2001), for classifying mixed variables on different scale levels. The two-step clustering algorithm is the best available technique to classify the continuous and mixed variables for a fixed number of clusters. The two-step clustering classification consists of two important steps. Initially, the total number of observations are grouped into sub-clusters and these are further considered as separate observations. The grouping is done by using hierarchical clustering with Euclidean distance as the criteria. The observations with smallest Euclidean distances are grouped into a single cluster. Euclidean distance can be calculated as the square root of the sum of the squared differences in the observations and can be expressed mathematically as in Eqn. (7)

$$d_{Euclidean}(BC) = \sqrt{(X_B - X_C)^2 - (Y_B - Y_C)^2} \quad (7)$$

In this clustering technique, either we can find the number of clusters or we can assign the required number directly to the algorithm. The sub-clusters are the basis for the second step analysis. In this step, K-means algorithm with log-likelihood distance measure is used for combining the clusters. The sample size required is greater than 200 in log-likelihood measure and it assumes the normal distribution of the continuous variables. The K-means clustering algorithm is performed many times in the second step and AIC or Akaike Information Criterion statistics is calculated for all the clustering combinations. The equation for calculating AIC is given in Eqn. (8).

$$AIC = 2k - 2\ln(L) \quad (8)$$

Where,
L is the maximum value of the likelihood function and
k is the number of estimated parameters

The silhouette is used to test the cohesiveness lies among data points those falls under the same category. The average silhouette value for the entire data set is the silhouette coefficient and its value lies between -1 to +1. For a better quality clustering, silhouette coefficient should be greater than 0.5 (Bhuyan, 2011).

Two step clustering was applied to speed ratio, which is the ratio of mean speed and free flow speed, the coefficient of variation and congestion index for two wheelers, three wheelers, and cars by using statistical software. The classification of speed ratio values attained by two-step clustering and the speed ratio ranges recommended by HCM 2010 are given in Table 4. The silhouette coefficient obtained is greater than 0.5 which is showing good quality cluster. The quality of clustering result is shown in Figure 4.

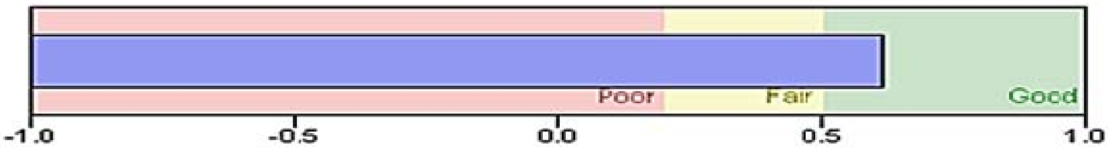


Figure 4: Silhouette Measure for Cluster Quality

Table 4: Level of Service Criteria Based on Speed Ratio Values

LOS classes	*Speed Ratio Classification*			
	Two step clustering result			*HCM 2010*
	Two wheeler	*Three wheeler*	*Car*	*Automobile*
A	> 0.83	>0.91	> 0.88	> 0.85
B	0.83 - 0.70	0.91-0.78	0.88-0.78	0.85 – 0.67
C	0.69 - 0.54	0.77-0.59	0.77-0.63	0.66 – 0.50
D	0.53 - 0.41	0.58-0.46	0.62-0.46	0.49 – 0.40
E	0.40 - 0.31	0.45-0.34	0.45-0.35	0.39 – 0.30
F	< 0.31	<0.34	< 0.35	< 0.30

Speed ratio ranges for automobiles obtained in the present study are different for two wheelers, three wheelers, and cars. Heterogeneous traffic condition is one of the reasons for this variation. The size, engine capacity, composition of traffic and width of the road affects the maneuverability of each type of vehicle. It is very interesting to note that the speed ratio ranges of two wheelers for each level of service are considerably less compared to the other modes. This is may be due to the high maneuverability of two wheelers facilitates to experience relatively high level of service under the given traffic condition. The maximum free flow speed observed for two wheeler is 63 km/hr and the same for three wheeler and the car is 56 km/hr and 62 km/hr respectively. The medium traffic condition is also giving variation in speed ranges likened with other modes and what given in HCM 2010. But in the congested condition, the opportunities for overtaking will reduce and the two-wheeler has to follow the preceding vehicle most of the time and hence the speed ranges are similar with HCM values for the level of service E and F.

Considering three wheelers the speed ratio 0.91 for the level of service A indicates that the free flow speed is not very large compared to the mean speed at lower flow condition because of the lower engine power and easily maneuvering nature of three-wheeler. The ranges of speed ratios are similar for three-wheelers and cars in most of the levels. The exciting reason is that in the urban flow condition the performance of these two categories of vehicles are similar since the overtaking opportunities are very minimum and they has to follow the front vehicle. The variation of clustering results of the car from HCM 2010 values may be due to the pedestrian influence, on-street parking, presence of bus stops and access points. When a bus stops for boarding and alighting of passengers, the car has to stop and wait for the bus to move forward because of the lack of bus bays in the study stretches. In the two lane two way roads the overtaking chances are least possible and thus all the vehicles have to follow the heavy vehicles including trucks and buses for a longer time till they get the suitable overtaking opportunity.

The coefficient of variation ranges from 4.34 to 58.49 for the study stretches. It is interesting to note that the two wheeler which is having the maximum maneuverability is having the highest limit of CV value (< 11.93) for level service ‘A’ condition. This is due to the probability of rapid driving fluctuations of two wheelers compared with the larger vehicles like three-wheelers and cars. The observation from the study is that in the lower flow condition, the variation in speed will be very less (< 9.02) and in the congested flow the variation will be more (> 53.21) for a car compared with three wheeler since the car drivers will prefer to travel with a constant speed without much fluctuations in lower flow condition. The driver behavior is having great influence in the coefficient of variation of speed which is difficult to measure quantitatively.

Congestion index directly gives the difference in free flow travel time and actual travel time while traveling through an urban road. The classification of congestion index in the present study clearly shows that the delay in three wheeler is less with reference to the other modes since the free flow speed of three wheeler is lesser (61 km/hr) due to the vehicle properties. The CI value range is more for a car (< 0.47) in the lower flow condition (LOS A) because of the lesser overtaking sight distance in two way two lane road. Cars have to follow the slower heavy vehicles for more duration for getting the overtaking opportunity and hence the delay increases. Table 5 shows the criteria for the level of service A to F in heterogeneous urban traffic condition. The silhouette coefficient obtained for two-step clustering is greater than 0.5 which is showing good quality cluster.

Table 5: Level of Service Criteria Based on Coefficient of Variation of Speed and Congestion Index by Using Two-Step Clustering

LOS classes	*Coefficient of Variation (CV)*			*Congestion Index (CI)*		
	Two wheeler	*Three wheeler*	*Car*	*Two wheeler*	*Three wheeler*	*Car*
A	< 11.93	< 10.30	< 9.02	< 0.33	< 0.28	< 0.47
B	11.93 - 26.05	10.30-21.48	9.02-21.17	0.33- 1.11	0.28-0.89	0.47-1.12
C	26.06 - 35.78	21.49-29.50	21.18-32.66	1.12 - 2.03	0.90-1.50	1.13-1.76
D	35.79 - 43.29	29.51-37.31	32.67-43.40	2.04 - 2.95	1.51-2.26	1.77-2.35
E	43.30 - 54.70	37.32-47.68	43.41-53.21	2.96 - 3.94	2.27-3.13	2.36-3.08
F	> 54.70	> 47.68	> 53.21	> 3.94	> 3.13	> 3.08

6. Conclusions

This study proposes a methodology to quantify the quality of traffic flow on two-lane undivided urban corridors by using the speed profile variation characteristics of automobiles. The speed profile of two-wheeler, three-wheeler, and the car was collected through a GPS-based mobile application. It was observed that under the same traffic flow conditions different automobile modes shows distinct speed profile pattern, indicates the unique level of service experience perceived by the individual mode users. Hence the level of service criteria was proposed for these three modes separately by using the two-step clustering technique.

The level of service criteria developed based on speed ratio values shows that different ranges of speed ratios for different modes under the same traffic condition. Again these observed speed ratio values were differing from the automobile LOS criterion values recommended by HCM 2010. Further, the level of service criteria was proposed based on the microscopic parameters like coefficient of variation (CV) of speed and congestion index (CI). The scope of the study is limited to the un-signalised two-lane two-way urban corridors with the observed traffic composition. Therefore the validity of the criterion values proposed depends on the roadway and traffic composition prevailing on the mixed traffic urban corridors. More such studies under varying roadway and traffic conditions are required to evolve a generalized LOS criteria for urban corridors. However, this study forms a basis to develop the LOS criteria for urban corridors under heterogeneous traffic conditions as prevailing in developing countries like India.

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