



Defining level of service criteria of urban streets in Indian context

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Abstract

Speed ranges of Level of Service (LOS) categories of urban streets are not well defined for highly heterogeneous traffic flow condition on urban streets in Indian context. In this respect, a study was carried out in the city of Mumbai, India and the result was tested on two major corridors in Kolkata City. Average travel speed on street segments is used as the measure of effectiveness, which in this case has been derived from second by second speed data collected using Global Positioning System (GPS) receiver fitted on mobile vehicles. Hierarchical Agglomerative Clustering (HAC) is applied on average travel speeds to define the speed ranges of urban street and LOS categories. Applying this methodology it is found that urban street speed-ranges of LOS categories valid in Indian context are different from that values specified in HCM (2000). The application of this procedure is that in a simple manner with the application of GPS it can be applied in the evaluation of level of service of urban streets in different environment.

Keywords: Level of service; Urban streets; Hierarchical agglomerative clustering; GPS; Heterogeneous traffic flow.

1. Introduction

The *Highway Capacity Manual* (HCM 2000) designates six levels of service for each type of facility, from A to F, with LOS “A” representing the best operating conditions and LOS “F” the worst. It uses distinct values as boundaries for the various levels of service, each of which represents a range of operating conditions. The classification of urban streets into number of street classes and speeds into different levels of service categories is well defined in HCM 2000 are well applicable in homogenous traffic flow condition. Hence, in this study it has been attempted to classify urban streets and speeds into number of categories that is applicable in the prevailing context of heterogeneous

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traffic flow. Traffic travels at reduced speed in heterogeneous traffic flow condition in India; whereas speed ranges defined in HCM 2000 are higher since it was developed in homogeneous traffic flow condition. Hence the speed ranges for urban streets in Indian context need to be defined. However if this methodology is applied in developed countries, the result may indicate LOS boundaries similar to the HCM 2000 values.

This study emphasizes on the easy and accurate way of speed data collection by the use of GPS as well as its applicability in defining speed ranges of LOS categories applicable in the present context. Though speed ranges are not well defined for LOS categories, it has been suggested by Indian Road Congress (1990) that on urban roads, the levels of service are strongly affected by factors like the heterogeneity of traffic, speed regulations, frequency of intersections, presence of bus stops, on-street parking, roadside commercial activities, and pedestrian volumes etc. Limited studies have carried out for heterogeneous traffic condition in India. Marwah and Singh (2000) have classified level of service into four groups (LOS I-IV). In another study for heterogeneous traffic condition on urban roads Maitra et al. (1999) redefined the LOS boundaries by quantifying congestion as measure of effectiveness.

Kikuchi and Chakroborty (2006) have reviewed the definitions of LOS categories that have been followed traditionally. The authors have examined the uncertainty associated with the measuring and mapping of existing six LOS categories. And six frameworks were formulated to address the uncertainty lies within six levels of service categories. Zolnik and Cromley (2006) have developed a poissoned- multilevel bicycle level of service methodology using the bicycle-motor vehicle collision frequency and severity in the GIS environment. This new methodology complements bicycle level of service methodologies on mental stressors by incorporating the characteristics of cyclists involved in bicycle - motor vehicle collisions as well as the physical stressors where bicycle-motor vehicle collisions occurred to assess bicycle, level of service for regional road network. Romana and Perez (2006) have used a threshold speed to assess LOS. The definition of threshold speed used “the minimum speed users consider acceptable in traveling on a uniform road section under heavy flows and platooning traffic”. The method used the same Measure of Effectiveness (MOEs) proposed by HCM, one reflecting percent time spent following (PTSF) and the second reflecting speed. However it has been suggested a threshold speed would be used to decide which MOE governs LOS in each period: if average travel speed (ATS) is higher than the threshold value, only PTSF would be examined, implying user consider the speed reasonable. If ATS is below the threshold speed, platooning would be behind speed in importance in the view of drivers.

Jensen and Trafitec (2007) have developed pedestrian and bicyclist satisfaction models using cumulative logit regression of ratings and variables. The model includes variables, which relate significantly to satisfaction ratings. Motorized traffic volume and speed, urban land uses, rural landscapes, type and width of pedestrians and bicyclist facilities, number and width of drive lanes, volume of pedestrians, bicyclists and parked cars, and also presence of median, trees and bus stops significantly influence the level of satisfaction. Models return percentage splits of six levels of satisfactions. These splits are then transferred into a level of service. Muraleetharan and Hagiwara (2007) have developed a methodology for estimating the overall LOS of pedestrian walkways and cross walks based on the total utility value, which came from a stated preference survey. Each sidewalk and crosswalk link was assigned with an overall LOS according to its operational and geometrical characteristics. The model result indicates that pedestrians

choose route not only for distance, but also for the overall LOS of sidewalks and crosswalks.

Xu et al. (1999) found that neural network-based macro taxi model gives much more accurate information on taxi services than the simultaneous equations model for Hong Kong urban areas. Madanat et al. (1994) have applied ordered probit model to find threshold values for each LOS categories using user perceptions. Cheol and Stephen (2002) used *K*-means, Fuzzy and SOM clustering in a real-time signalized intersection surveillance system for the determination of LOS categories. Lingra (1995) compared grouping of traffic pattern using the Hierarchical Agglomerative Clustering and the Kohonen Neural Network methods in classifying traffic patterns. In this study it has been observed the advantage of hierarchical grouping on a small subset of typical traffic patterns to determine the appropriate number of groups. Also, Lingra (2001) applied Hierarchical Agglomerative Clustering technique and an evolutionary Genetic Algorithms approach for the classification of highway sections. It has been pointed out that hierarchical approach tends to move farther away from the optimal solution for smaller number of groups.

Generally, average travel speed on street segments is used as the measure of effectiveness for defining speed ranges of LOS categories. The use of moving observer method is the most commonly used technique for the collection of travel speed data. However, limitation to the use of moving observer method is that accuracy in data collection varies from technician to technician. The use of GPS in this study helps in gathering large amount of speed data collected second wise which is better than traditional techniques. Accurately collected speed data were easily managed in the GIS environment. The collected data are used to find the free-flow speed ranges of urban street classes and speed ranges of levels of service categories as these are not well defined for heterogeneous traffic flow condition in Indian context.

While carrying out a thorough study in this context, this paper presents a methodology for defining speed ranges of level of service categories of urban street classes. Urban streets are classified into four classes using the free flow speeds data averaged over each street segments comes under the study area. Also, the travel speeds averaged on each street segment were classified into six levels of service categories. Consequently this study demonstrates the potential use of average travel speed as a measure of effectiveness for assessing the level of service of urban streets. The average travel speed on segments, is derived from second by second speed data collected using Global Positioning System (GPS) receiver fitted on mobile vehicles traveled on major corridors in the city of Mumbai, India. . However, in order to justify the applicability of this level of service criteria, similar set of data were collected for Kolkata City. Speed ranges of level of service categories developed for Mumbai city are also well applicable to Kolkata City. With the capability to obtain average travel speed by direct field measurement method using GPS fitted with mobile vehicle system, the possibility of obtaining new LOS criteria that can be used for urban street analysis emerges. The methodology for applying hierarchical agglomerative clustering and validation parameter 'Silhouette' has been demonstrated by finding cohesiveness that lies among speed data points while fixing speed ranges for LOS categories. Five major road corridors comprising of 100 street segments in Mumbai city, operating under mixed traffic are taken for this study. The following section provides brief review of the Hierarchical Agglomerative Clustering technique and its validation measure. The remaining sections describe the application of hierarchical agglomerative clustering

methodology, study corridors and methods of data collection, analysis of the collected data, results obtained, summary and conclusions.

2. Hierarchical Agglomerative Clustering (HAC) Methodology

Cluster analysis, also called data segmentation, has a variety of goals. All relate to grouping or segmenting a collection of objects (also called observations, individuals, cases, or data rows) into subsets or "clusters", such that those within each cluster are more closely related to one another than objects assigned to different clusters. Central to all of the goals of cluster analysis is the notion of degree of similarity (or dissimilarity) between the individual objects being clustered. Hierarchical agglomerative cluster analysis is a statistical method for finding relatively homogeneous clusters of cases based on measured characteristics. It starts with each case in a separate cluster and then combines the clusters sequentially, reducing the number of clusters at each step until only one cluster is left. The following three steps were followed to perform Hierarchical Agglomerative Clustering (HAC) on free flow speed data using the statistics toolbox in MATLAB to classify urban streets into four classes and on average travel speeds into six levels of service categories.

2.1 Step 1: Finding the Similarity between Objects

The similarity between objects (speeds) is calculated by the use of distance function. For a data set made up of m objects, there are $m \times (m-1)/2$ pairs in the data set. For example, consider a sample data set, X , made up of six objects {say average free flow speed (ffs) values in kmph on six street segments}. The data set can be defined as a matrix:

$$X = [\text{ffs}_1; \text{ffs}_2; \text{ffs}_3; \text{ffs}_4; \text{ffs}_5; \text{ffs}_6] = [85.00; 92.56; 72.85; 50.66; 39.89; 38.58].$$

While applying HAC, the distance function calculates the distance between ffs_1 and ffs_2 , ffs_1 and ffs_3 , and so on until the distances between all the pairs have been calculated. The distance function returns the information such that each element contains the distance between pair of objects (ffs) can be represented by a distance vector say Y .

$$Y = \begin{bmatrix} \text{ffs}_{1-2} & \text{ffs}_{1-3} & \text{ffs}_{1-4} & \text{ffs}_{1-5} & \text{ffs}_{1-6} & \text{ffs}_{2-3} & \text{ffs}_{2-4} & \text{ffs}_{2-5} & \text{ffs}_{2-6} & \text{ffs}_{3-4} & \text{ffs}_{3-5} \\ \text{ffs}_{3-6} & \text{ffs}_{4-5} & \text{ffs}_{4-6} & \text{ffs}_{5-6} & & & & & & & \\ 7.56 & 12.15 & 34.34 & 45.11 & 46.42 & 19.71 & 41.90 & 52.67 & 53.98 & 22.19 & 32.96 \\ 34.27 & 10.77 & 12.08 & 1.31 & & & & & & & \end{bmatrix}.$$

The distance vector can also be reformatted into a matrix to make it easier to see the relationship between the distance information generated by the distance function and the objects in the original data set. In this study, the distance function is applied two times to compute the dissimilarity between every pair of speed data. Firstly, on the free-flow speed data averaged over each street segments and secondly on the congested speed data. There are several distance functions like City block or Manhattan, Minkowski,

Cosine, Correlation, Hamming, Jaccard and Euclidean to calculate the dissimilarity matrix. In this study “Euclidean distance” was used as the measuring distance.

2.2 Step 2: Defining the Links between Objects

Once the proximity between objects in the data set has been computed, it can be determined how objects in the data set should be grouped into clusters, using the linkage function. The linkage function takes the distance information generated by the distance function and links pairs of objects that are close together into binary clusters. The linkage function then links these newly formed clusters to each other and to other objects to create bigger clusters until all the objects in the original data set are linked together in a hierarchical tree. For example, given the distance vector Y generated by distance function from the sample data set of ffs, the linkage function generates a hierarchical cluster tree, returning the linkage information in a matrix, Z .

$$Z =$$

5	6	1.31
1	2	7.56
4	7	10.77
3	8	12.15
9	10	22.19

In this output, each row identifies a link between objects or clusters. The first two columns identify the objects that have been linked. The third column contains the distance between these objects. For the sample data set of ffs, the linkage function begins by grouping objects 5 and 6, which have the closest proximity (distance value = 1.31). The linkage function continues by grouping objects 1 and 2, which have a distance value of 7.56.

The third row indicates that the linkage function grouped objects 4 and 7. If the original sample data set contained only six objects, which is the object 7? Object 7 is the newly formed binary cluster created by the grouping of objects 5 and 6. When the linkage function groups two objects into a new cluster, it must assign the cluster a unique index value, starting with the value $m+1$, where m is the number of objects in the original data set. (Values 1 through m are already used by the original data set.) Similarly, object 8 is the cluster formed by grouping objects 1 and 2. Linkage uses distances to determine the order in which it clusters objects. The distance vector Y contains the distances between the original objects 1 through 6. But linkage must also be able to determine distances involving clusters that it creates, such as objects 7, 8, 9 and 10. By default, linkage uses a method known as single linkage. However, there are a number of different methods available. The linkage function grouped object 8, the newly formed cluster made up of objects 1 and 2, with object 3 from the original data set. Similarly, the linkage function grouped object 9, the newly formed cluster made up of objects 4 and 7, with object 10, the newly formed cluster made up of objects 3 and 8.

Valid cluster links objects in the cluster tree that has strong correlation with the distances between objects in the distance vector. And, the cophenet function was used to compare these two sets of values and compute their correlation, returned a value called the cophenetic correlation coefficient. The closer the value of the cophenetic correlation coefficient is to 1, the better the clustering solution.

The cophenetic correlation between Z and Y is defined as

$$C = \frac{\sum_{i < j} (Y_{ij} - y)(Z_{ij} - z)}{\sqrt{\sum_{i < j} (Y_{ij} - y)^2 \sum_{i < j} (Z_{ij} - z)^2}} \quad (1)$$

where:

Y_{ij} is the distance between objects i and j in Y ,

Z_{ij} is the distance between objects i & j in Z ,

y and z are the average of Y and Z respectively.

The cophenetic correlation coefficient is highest for ‘average’ linkage type using the average travel speed data hence used in this study.

2.3 Step 3: Creating Clusters

The hierarchical, binary cluster tree created by the linkage function is most easily understood when viewed graphically. The Statistics Toolbox function dendrogram plots the tree using the example data set is shown in the Figure 1. In the figure, the numbers along the horizontal axis represent the indices of the objects (ffs₁; ffs₂ etc.) in the original data set. The links between objects are represented as upside-down U-shaped lines. The height of the U indicates the distance between the objects. For example, the link representing the cluster containing objects 5 and 6 has a height of 1.31. The link representing the cluster that groups object 3 together with objects 1 and 2 (which are already clustered as object 8) has a height of 12.15. In this step, the hierarchical tree was cut at the desired point to form the required number of clusters using the cluster function. For example, in Figure 1 when the dendrogram is cut at a height of 15, two clusters will be formed. The cluster 1 comprises of 3 objects (ffs₁; ffs₂; ffs₃) and cluster 2 comprises of 3 objects (ffs₄; ffs₅; ffs₆). In this study, the cluster function was applied five times; once for the free-flow speed data and four times on the speed data of urban street classes.

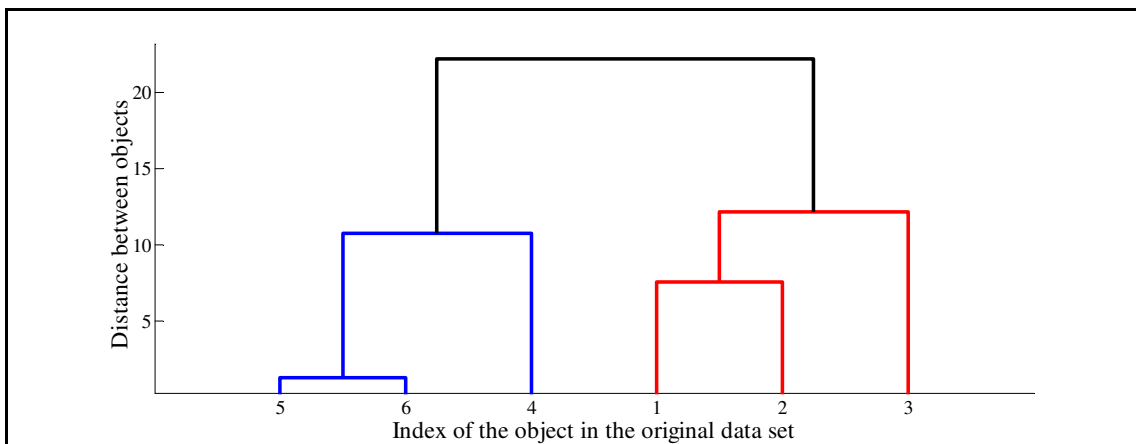


Figure1: Typical Dendrogram using sample free flow speeds data.

3. Study Corridors and Data Collection

3.1 Study Corridors

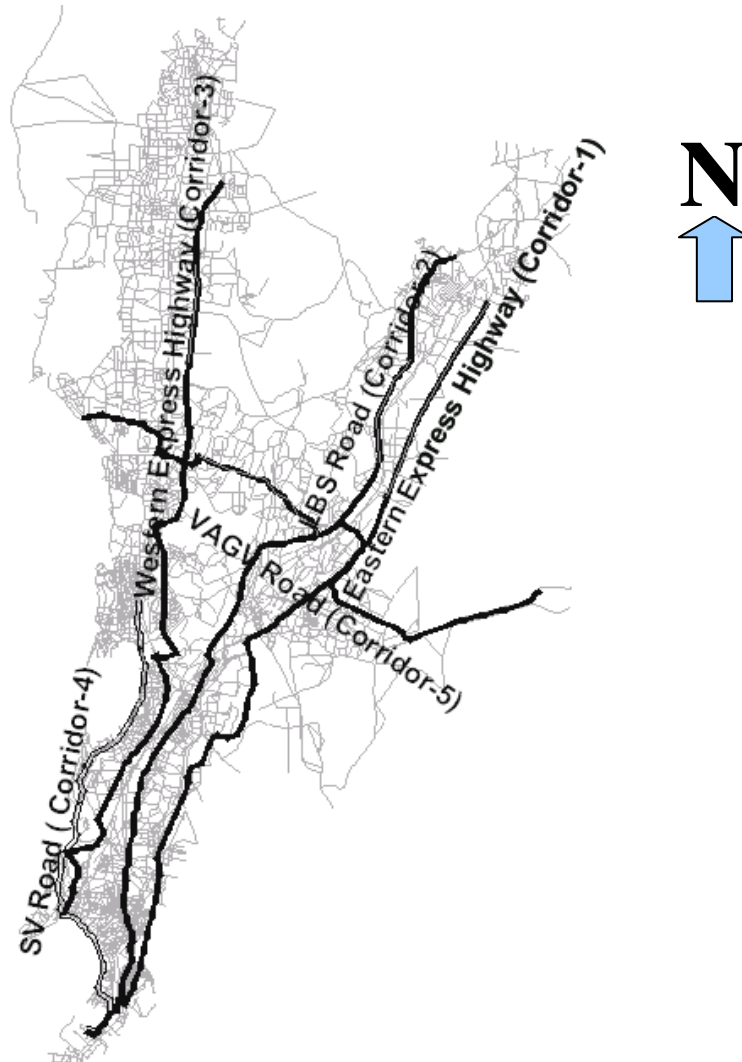


Figure 2: Map showing selected corridors of Greater Mumbai.

The base year road network of the study area is prepared in GIS environment. Additional attributes on the road network were added to the base map by conducting a road inventory survey. Five important urban road corridors of the city of Mumbai of Maharashtra State, India are selected for the present study. Greater Mumbai is an Island city with a linear pattern of transport network having predominant North-South commuter movements. Passengers move towards south for work trip in the morning hours and return back towards north in the evening hours. Hence four north-south corridors and one east-west corridor comprising of 100 street segments have been chosen for the present study. Major roads like Eastern express highway extending up to south (Corridor-1), LBS Road extending up to south via Ambedkar road (Corridor-2), Western express highway extending up to marine drive (Corridor-3), SV road extending up to south via Veer Savarkar road (Corridor-4) and Versova- Andheri- Ghatkopar-

Vashi (VAGV) (Corridor-5) are included. These are shown on the GIS base map in Figure 2. In order to show the applicability of this study in other cities of India a similar survey was carried out in Kolkatta City. Two corridors having varying geometric and surrounding environmental characteristics were taken into considerations i.e. one corridor was Airport to Joka and the other corridor was Airport to Ulberia. These two corridors are approximately 80 kilometer length; comprised of 50 street segments and the data were collected during August, 2009. The interesting fact on selecting these two cities for this study is that traffic composition and road geometric characteristics along with functionality brings the true variation that was required for this purpose.

3.2 Data Collection

The probe vehicle used in this study was mid-sized car. This vehicle was fitted with Trimble Geo-XT GPS receiver, capable of logging speed data continuously at time intervals of one second. The survey was conducted during March and April of the year 2005. GPS provides both spatial and time/distance based data from which various traffic parameters were derived, including travel time and travel speeds. In order to get unbiased data sets three mid-sized cars were used and help of three drivers on different days of the survey work was taken. Basically three types of data sets were collected. The first type is roadway inventory details, for which a data dictionary was prepared using Pathfinder office 3.0. During the collection of inventory details proper segmentation technique was applied, which is just after signalized intersection to just after next signalized intersection. Details on segments like segment number, number of lanes, median types, pedestrian activity, road side development, access density, construction activity, speed limit, separate right turn lane, number of flyovers, date and day of data collection and segment length were collected. From the inventory data, it was found that most of urban street segments are four lane divided type. On street parking of vehicles, pedestrian activities coupled with commercial activity of vendors are affecting the smooth movement of the vehicles considerably. Inadequate road infrastructure with lack of enforcement in traffic rule and regulations are bringing traffic into a chaotic condition during peak hours on these corridors.

The second type of survey conducted was to find the free flow speed. Before going for the free flow speed data collection, we should know when the traffic volume is less than or equal to 200 vehicles per lane per hour. A detailed 24 hour traffic volume count survey was conducted by this group for Western Freeway Sea- Link (WFSL) project in the month of April 2005. The traffic volume data were collected on 45 stations on seven screen lines. From this survey data, traffic volume per lane per hour was calculated for roads coming under this study area. It was found that free flow traffic condition (less than 200veh/ln/hr) is approaching at 12 mid-night and all road sections are having free flow traffic conditions from 1 AM to 5 AM. Hence free flow speed for all these corridors were collected during these hours. The third type of data collected was congested travel speed. Congested travel speed survey was conducted during both peak and off-peak hours on both directions of all corridors. Number of trips covered for each direction of travel and for the study hours (peak, off-peak and free-flow) is at least 3 and sometimes it is up to six trips. After data has been collected in the field, it has been transferred back to the office computer by using Pathfinder office version 3.00. Accuracy of field data were significantly improved through a process called *differential correction*. This requires a set of base files those are collected at a known location at the

same time that field data (rover) files were collected. For this study, we collected the base files from remote sensing division, department of civil engineering, IIT Bombay. Data were visually checked before exported to a GIS or spatial database. This was to confirm that all the expected data were there, and was looked for any unwanted positions. Further, GPS data were incorporated into a GIS based transportation software called TransCAD. Similar method was applied to the data collected from Kolkata city also.

4. Validation measure

Cluster validity refers to the problem whether a given partition fits to the data at all. The clustering algorithm always tries to find the best for a fixed number of clusters and the parameterized cluster shapes. However this does not mean that even the best fit is meaningful at all. Either the number of clusters might be wrong or the cluster shapes might not correspond to the groups in the data, if the data can be grouped in a meaningful way at all (Bensaid et al. 1996; Bezdek and Pal 1998). Silhouette is used in testing the cohesiveness lies among speed data points those falls under same category.

4.1 Silhouette

The graphical representation of each clustering is provided displaying the silhouettes introduced by Rousseeuw (1987). The entire clustering is displayed by plotting all silhouettes into a single diagram, allowing us to compare the quality of the clusters. Therefore, the silhouette shows which objects lie well within their cluster and which ones are merely somewhere in between clusters. A wide silhouette indicates large silhouette values and hence a pronounced cluster. The other dimension of a silhouette is its height, which simply equals the number of objects in a group. In order to obtain an overview, the silhouettes of the different clusters are printed below each other. In this way the entire clustering can be displayed by means of a single plot, which enables us to distinguish clear-cut clusters from weak ones. The average of the silhouettes for all objects in a cluster is called the *average silhouette width* of that cluster. The average of the silhouettes for the entire data set is called the *average silhouette width for the entire data set*. The choice of optimal number of clusters is one of the most difficult problems of cluster analysis, for which no unique solution exists. This *average silhouette width for the entire data set* should be as high as possible, is used for the selection of optimal number of clusters. For application this maximum value of *average silhouette width for the entire data set* is called the *silhouette coefficient*. The silhouette coefficient is a dimensionless quantity which is at most equal to 1.

5. Results and Analysis

Average travel speed was calculated direction-wise on each segment. Hierarchical Agglomerative Cluster analysis was applied in two stages. First on average free flow speed on all segments and corresponding range of free-flow speed were found for each

urban street class. Second on congested average travel speed on each segment for both peak and off-peak hours and corresponding speed ranges were found for LOS categories. While applying Hierarchical Agglomerative Clustering method on speed data “Euclidian distance” was used as the measuring distance on speed values. Various linkage types were tested through the statistical measuring parameter Cophenetic Coefficient (CC) to find out the best linkage type whose value approaches to one. Cophnetic Coefficient values for various linkage types are calculated and “Average linkage” type was selected because of maximum CC value among all. Hierarchical tree of binary clusters was divided into larger clusters using the cluster function. The hierarchical cluster tree (dendrogram) formed out of free flow speed data was cut off at a level where it formed five clusters.

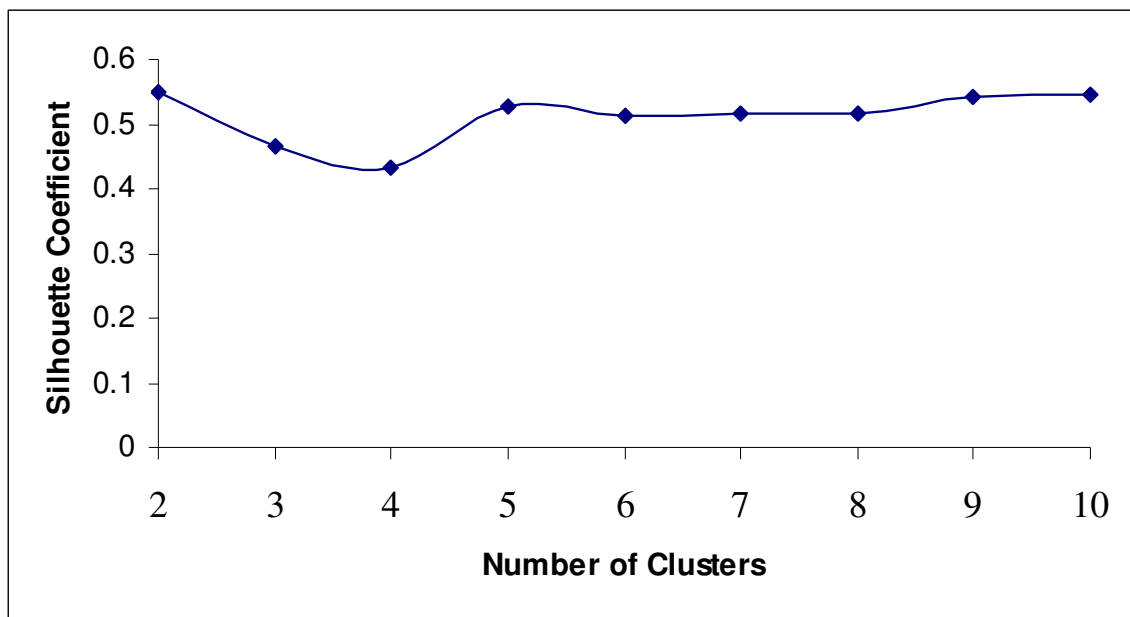
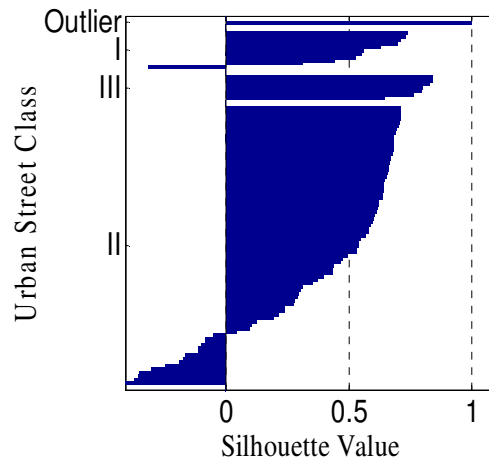
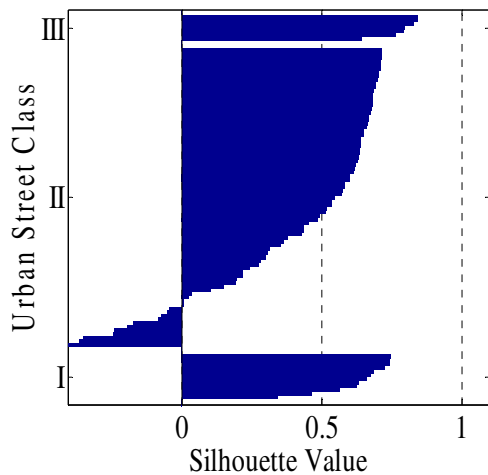


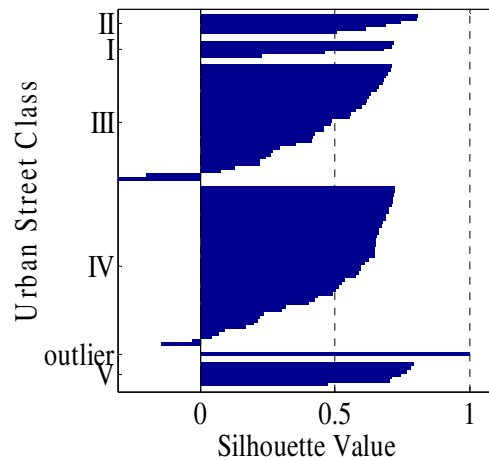
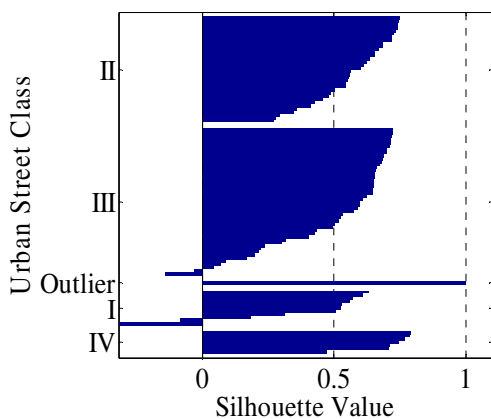
Figure 3: Silhouette Coefficient for finding Optimal Clusters used in Urban Street Classification.

The heuristic reasoning is that the silhouettes should look best for a “natural” number of clusters. Hence, silhouette is used as the validation measure in finding optimal number of clusters and degree of cohesiveness that exist in inter-cluster and intra-cluster data points. One way to choose appropriate number of clusters is to select that value of cluster for which silhouette coefficient is as large as possible. At the same time it is considered that partitions with lesser clusters are better, when the differences between the values of validation measures are minor as number of cluster increases. While finding optimal number of clusters using silhouette coefficients as shown in Figure 3, it turns out that the best choice is when number of clusters is 5. The silhouette coefficient equals 0.527 at this cluster number five and according to previous discussion, it is interpreted that a reasonable good structure has been exist while clustering the free-flow speed data points to find urban street classes. One should never merely accept a high overall average silhouette width as its face value, but also look at the graphical output itself to find out what caused the large value. In order to look into degree of cohesiveness that lies within urban street classes, silhouettes were plotted for each free-flow speed. In Figure 4 (A) and 4 (B) for three and four urban street classes it is found that urban street class II is not well classified in both cases because they contains large

number of negative silhouette values. Comparing Figure 4 (C) and 4 (D) it is interpreted that best cluster partition lies when urban street is classified into five classes which was further justified by Figure 3. In conclusion, the silhouette plots tell us that a partition into five clusters is probably most natural. But out of five classes one is considered as an outlier because in this group only a single free flow speed data point lies. Depending on the subject matter and task at hand, we wanted to put the outlier aside for further investigation and classified urban street into four classes.



A: Silhouette Values for Three Urban Street Classes B: Silhouette Values for Four Urban Street Classes



C: Silhouette Values for Five Urban Street Classes D: Silhouette Values for Six Urban Street Classes

Figure 4: Silhouette Values used in Urban Street Classification.

As in HCM (2000), further justified by optimal clustering criteria it has been attempted to categorize the urban streets into four classes based on free flow speed, geometric and surrounding environmental characteristics in the present context. Free flow speed ranges for four urban street classes are obtained in the present context. Speed ranges for level of service categories of urban street classes (I-IV) obtained in Indian context are shown in Figure 5. These results are also shown in Table 1. Silhouette Values for Urban street classes are plotted and it was found that average Silhouette width lie between 0.35 and 0.75 for all street classes. This indicates that reasonable classifications have been presented.

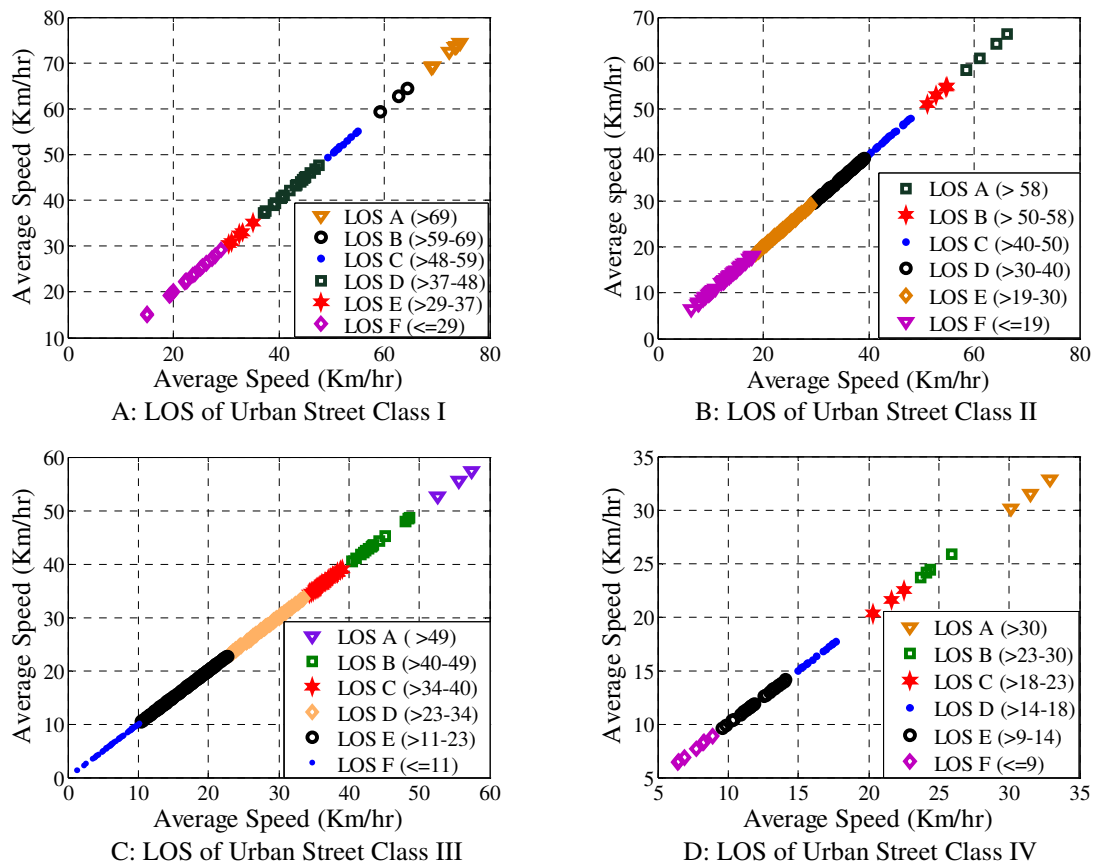


Figure 5: HAC of Average Travel Speeds for Level of Service of Urban Street Classes (I-IV).

Table 1: Urban Street Speed Ranges for different LOS Proposed for Indian Conditions using Hierarchical Agglomerative Clustering.

Urban Street Class	I	II	III	IV
Range of Free Flow Speed (FFS)	68 to 85 km/h	54 to 68 km/h	38 to 54 km/h	25 to 38 km/h
Typical FFS	75km/h	60km/h	50km/h	35 km/h
LOS	Average Travel Speed (Km/h)			
A	>69	>58	>49	>30
B	>59-69	>50-58	>40-49	>23-33
C	>48-59	>40-50	>34-40	>18-23
D	>37-48	>30-40	>23-34	>14-18
E	>29-37	>19-30	>11-23	>9-14
F	≤29	≤19	≤11	≤9

It can be inferred from Figure 6 that reasonable good classification has been found for urban street classes and level of service categories. Looking at this figure it is interpreted that vehicles move at congested level of service of “D”, “E” and “F” on all these street classes more frequently because silhouette heights are more.

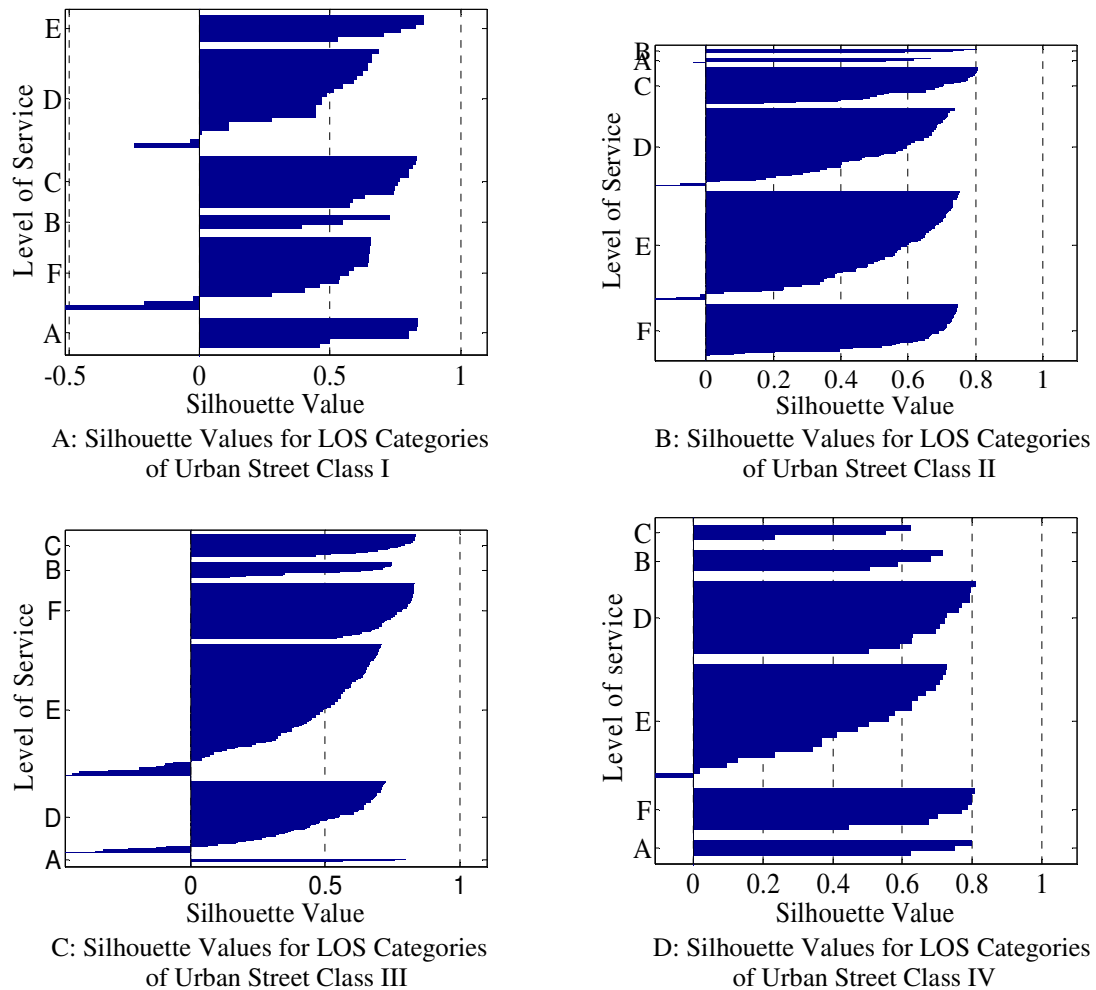


Figure 6: Silhouette Values for LOS Categories of Urban Street Classes (I-IV).

In order to check the application of this level of service criteria; data collected in Kolkata city were tested. Free flow speed and average travel speed during both peak and off-peak hours on each of segments on both corridors were calculated. The street segments were classified into four classes based on free-flow speed, geometric and surrounding environmental characteristics. Also, levels of service provided by the street segments during peak and off peak hours were estimated using Table 1 shown above. The percentage of travel runs under different levels of service categories found for urban street classes in Kolkata city during the survey period are shown in Table 2. From this table it has been observed that the observed vehicle traveled at better quality of service under urban street class I, whereas under other urban street classes the observed vehicle traveled at medium quality of service during the observed period. Average travel speeds for level of service categories expressed in percentage of free- flow speeds are calculated and the same are shown in Table 3. Values found using HAC method for the present context is compared with those values mentioned in HCM (2000) and IRC (1990). From this table it is found that there lies reasonable difference in the percentage values valid for Indian condition and those values mentioned in HCM (2000) and IRC (1990).

Table 2: Percentage of travel runs under different levels of service categories for urban street classes in Kolkata city.

Level of Service	Urban Street Class			
	I	II	III	IV
A	52.78	0.00	3.92	15.56
B	30.56	22.22	11.76	24.44
C	8.33	22.22	21.57	22.22
D	2.78	22.22	31.37	17.78
E	2.78	27.78	19.61	6.67
F	2.78	5.56	11.76	13.33

Table 3: Comparison of Percent FFS Values for each LOS Categories as obtained using HAC Method.

Level of Service	% FFS (HCM, 2000)	% FFS (IRC, 1990)	% FFS (HAC Method)	Typical % FFS (HAC Method)
A	90	90	85-95	90
B	70	70	75-90	80
C	50	50	60-75	70
D	40	40	45-60	55
E	33	33	35-45	40
F	25-33	25-33	20-35	20-35

6. Conclusion

Similar to the classifications adopted in HCM (2000) and satisfying to local conditions, the urban streets in the present context are classified into four classes and free-flow speed ranges were fixed for each urban street class. Secondly, cluster analysis is applied on both peak and off-peak hour traffic speed data and speed ranges for level of service categories were found out. It has been found from this study that urban street speed-ranges valid in Indian context are different from the corresponding values mentioned in HCM (2000). These differences are due to the heterogeneous nature of traffic flow along with varying geometric characteristics of road sections. From this result it has been found that typical average travel speed for LOS categories expressed in terms of the percentage of free flow speed for level of services “A”, “B” and “C” are comparatively higher to that values mentioned in HCM (2000). But these good qualities of service happen for lesser period of time on these study corridors. The probe vehicle travelled at level of service of “D”, “E” and “F” for more frequently. The limitation of this study is that we need large number of speed data points in order to get better result in classifications.

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