Defining Level of Service Criteria of Urban Streets using Divisive Analysis (DIANA) of Hierarchical Clustering and GPS Data in Indian Context

Vivek Kumar Gope, Prasanta Kumar Bhuyan

Abstract -- Level of Service (LOS) for heterogeneous traffic flow on urban streets is not well defined in Indian Context. Hence in this study an at tempt is taken to classify urban road networks into number of street classes and average travel speeds on street segments into LOS categories. Divisive Analysis (DIANA) of Hierarchical Clustering is used for such classification of large amount of speed data collected using GPS receiver. DIANA algorithm and silhouette validation parameter is used to classify Free Flow Speeds (FFS) into optimal number of classes and the same algorithm is applied on speed data to determine ranges of different LOS categories. Speed ranges for level of service categories (A-F) expressed in percentage of free-flow speeds were found to be 89, 72-89, 53-72, 40-53, 25 and 20-25 respectively in the present study. Whereas, in HCM (2010) it has been mentioned these values are 85 and above, 67-85, 50-67, 40-50, 30-40 and 30 and less percent respectively.

Index terms – Leve of Service, Divisive Analysis, Urban streets, DIANA, GPS, Free Flow Speed

1 Introduction

The traffic and transportation facility of any country significantly defines its development. The developing countries like India must have a well defined LOS analysis procedure to develop a good road network. Because, it is very essential for the planning, design of transportation system and allocation of limited resources to the competing projects. The FFS ranges for urban street classes and speed ranges of LOS categories that are specified in HCM (2000) [1] have been followed in India for LOS analysis of urban streets. In fact, speed ranges mentioned in HCM (2000) are suitable for developed countries having homogenous traffic flow. In developing countries like India traffic on roads are highly heterogeneous, twenty-two types of vehicles having wide variation in physical size travels on roads. As a result of which vehicular travel speed is comparatively less under heterogeneous flow condition.

In transportation engineering, according to HCM-2010 [2] “Level of Service (LOS) is a quantitative stratification of a performance measure or measures that represent quality of service. The measures used to determine LOS for transportation system elements are called service measures.”. The HCM designates the Urban street facilities into six different types of LOS ranging from “A” to “F”. LOS-A represents the best quality of road and hence best serviceability and LOS-F represents the worst facility.

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The Urban street classification or LOS is based on average through-vehicle travel speed for that segment or for the entire street under consideration.

As LOS is not well defined for highly heterogeneous traffic flow on urban streets in India, an attempt has been made to define LOS criteria in this study. Average travel speed of through-vehicles for segments under each street corridor is the basis of defining LOS of urban streets. Traditionally, for collecting travel time data probe vehicle is used but this method is quite susceptible to human error. The best way of collecting data is by moving-observer method. However, accuracy with this technique varies from technician to technician. The location can be pointed according to their longitude- latitude and GPS gives the accurate measure of their position and hence travel-speed data can be recorded at different points. GPS receivers can record location and speed automatically at regular sampling periods; hence a considerable data can be collected in terms of travel speed and travel time.

Defining LOS of urban street classes is basically an approach to classify average travel speeds on road segments of the entire road network into number of groups. From literature review it was found that cluster analysis is the most suitable technique for the classification of the large amount of speed data acquired through GPS receiver. In this study Divisive Analysis (DIANA) of Hierarchal Clustering is used for the classification of data set. The data set used in this study was obtained from 10 to12 travel runs taken on five major urban corridors in the city of Mumbai, India. The total length of these corridors is about 140 km. These corridors, on the whole, were divided into 100 street segments. Comprehensive data sets of free-flow speed, travel speeds during both peak and off- peak hours, inventory details and classified traffic volume data were used. The clustering algorithm was used twice in this research. First, DIANA clustering was used on Free Flow Speed (FFS) data to get FFS ranges of urban street classes. After defining the speed ranges DIANA was used for the second time on average travel speed data to get the speed ranges of different LOS categories. To get the optimal number of cluster using FFS data silhouette width was used as Validation parameters. The coherence of the clustering result for the classification of urban streets and LOS categories were verified with geometric and surrounding environmental characteristics of street segments. Analyzing the data it is found that urban street segments can be classified into four classes in Indian context. The speed limits of LOS categories are proportionately lower than that values mentioned in HCM 2000 and speed values expressed in terms of percentage of FFS are marginally different from those mentioned in HCM (2010).

2 REVIEW OF LITERATURE

The current definition of LOS being followed is that defined in 2000 HCM (TRB,2000). Level of service in the Highway Capacity Manual (HCM 2000) defined as ‘‘a quality measure describing operational conditions within a traffic stream, generally in terms of service measures such as speed and travel time, freedom to maneuver, traffic interruptions, comfort and convenience.’’ Several studies have been performed on LOS analysis of urban street classes. Flannery et.al (2008) [3] incorporated user perception to estimate LOS of Urban street facilities using a set of explanatory variables that describe the geometry and operational effectiveness. Aras an and Verdigris (2010) [4] through computer simulation studied the effect of a dedicated bus lane on the LOS of heterogeneous traffic condition prevailing in India. The author also estimated the probable modal shift by commuter when a dedicated bus lane is introduced. Clark (2008) [5] from his study upon New Zealand traffic questioned about the LOS “F”. The author suggested for a new LOS to be termed as F+ or G specially refers to the type of traffic condition prevailing in New Zealand.

Shao and Sun (2010) [6] proposed a new concept on LOS. The author categorized LOS into two parts: Level of facility supply and Level of traffic operation. Travel speed to free flow speed ratio was considered as evaluation index of traffic operation. Fuzzy set was used by authors to categorize traffic operation into different groups. So the authors developed a state-of-the-art hybrid algorithm for this purpose and classified urban roads based on vehicle track and infrastructural data collected through GPS. Landan et. al. (2007) [7] did not consider traffic flow as the only parameter to access the LOS of various traffic facilities. Not going with traditional research the author analyzed the pedestrian LOS with user perception along with physical facilities and traffic flow operation. In this research the authors have elaborated that primary factors for classification of LOS can be determined by utilizing mass survey data and statistical software SPSS. Shouhed et.al. (2009) [8] found that the LOS criteria of walkways proposed by HCM 2000 are not suitable for China. The authors have taken user perception into consideration for classification of LOS at urban rail transit passages and found the limit for LOS standards suitable for China which is lower than that suggested by HCM 2000. In this study it has been found that body size, culture, gender and age influence the LOS classification. Fang and Paychex (2009) [9] studied on LOS of signalized intersections taking user perception into account. Unsupervised data clustering technique such as fuzzy c-means clustering was used to get distinct cluster of user perceived delay and service rating.

Clustering result was analyzed according to approach membership, delay membership and rating membership. Flannery, A. et. al. (2005) [10] have attempted to compare the quality of service assessed by drivers on the performance of the urban streets with the defined LOS categories for different services. The study revealed that the current means of calculating LOS (following HCM 2000) accounts for 35% of the mean driver ratings. Therefore, other factors play a role in driver’s assessment of quality. Multiple factors are highly correlated with the mean driver ratings, including those related to operations (average speed), design (the presence of median), and aesthetics (the presence of trees). Animi, M. and Zhang, Y. (2010) [11] have applied three pattern recognition methods (K-means, fuzzy C-means, and CLARA (clustering large applications)) to classify freeway traffic flow conditions on the basis of flow characteristics. The classification results from the three clustering methods were compared with the HCM 2000 LOS. Briton, W. and Estela, A. (2010) [12] have presented standardized methods that allow a differentiated evaluation of saturated flow (LOS F) conditions beyond a static consideration of traffic conditions in German Highway Capacity Manual. All the methods described can theoretically be adopted for the evaluation of operational quality on urban roads as well as for signalized and priority intersections. Roes, R. P. et. al. (2010) [13] have authored “Level of Service 2010 and beyond” and attempted to address on the history of the LOS concept and its use in the planning, design, and analysis of traffic facilities. Ko, B. et. al. (2009) [14] have conducted an extensive survey to know the performance measures that significantly affect truck driver's perceptions of LOS on various roadway types. It has been identified various performance measures through the analysis of survey data and the results lay the ground- work for future research that can focus on the actual development of quantitative methods for truck mode. Chen, X. et. al. (2009) [15] have developed a methodology using Fuzzy Neural Networks to access the LOS perceived by road users at signalized intersections. In this study, a neural network containing fuzzy reasoning experiences was employed to combine the perceived attributes in order to determine LOS. Cao, S. et. al. (2009) [16] have conducted a stated preference survey to study the factors influencing the LOS perceived by passengers at Platforms of Beijing Urban Rail Transit. In this research, it has been observed that congestion level of the platform was the most important factor influencing the LOS of the platform, followed by passenger order, air quality, information signs, and waiting time. Zegree, J. D. et. al. (2008) [17] have developed default values to represent input parameters to the approach methodology used in the analysis of Capacity and Level of Service of roads when they are difficult to measure or estimate. It has been observed that out of several default parameters, nineteen parameters have shown high degree of sensitivity in influencing service measure results in the appropriate methodology. Dowling, R. et. al. (2008) [18] have developed a methodology for the assessment of the quality of service provided by urban streets for the flow of traffic by various modes on the road network at national level. In this research the authors have categorized urban travels into four types (motorized vehicle, transit mode, bicycle rider, and walk mode) and hence developed separate LOS models for each mode of travel. Chakraborty and Kikuchi (2007) [19] utilized Fuzzy set in order to find the uncertainty associated with the LOS categories. Six frameworks were proposed by the authors in order to determine the uncertainty associated under each LOS category. The author found that it is appropriate to differentiate LOS into six categories as described in HCM but proposed a new six levels of service by merging existing LOS A and B and splitting existing LOS. LOS F into two categories. Patnaik and Ramesh Kumar (1996) [20] developed methodology to define level of service of urban roads taking into account users' perceptions. These are some of researches carried out at different locations under different traffic conditions which give a strong back ground for further research carried out in this study in defining LOS criteria in Indian Context.

3 DIVISIVE HIERARCHICAL CLUSTERING

3.1 DIANA- It is a hierarchical clustering technique which constructs the hierarchy in the inverse order. It approaches the reversal algorithm of Agglomerative Hierarchical Clustering. There is one large cluster consisting of all n objects. At each subsequent step, the largest available cluster is split into two clusters until finally all clusters, comprise of single objects. Thus, the hierarchy is built in n-1 steps. In the first step of an agglomerative method, all possible fusions of two objects are considered leading to n(n-1)/2 combinations. In the divisive method based on the same principle, there are $2^{n-1}-1$ possibilities to split the data into two clusters. This number is considerably larger than that in the case of an agglomerative method. To avoid such large calculations, we go with following steps:

1. Find the object, which has the highest average dissimilarity to all other objects. This object initiates a new cluster– a sort of a **splinter group**.
2. For each object **I** outside the **splinter group** compute: -
   D_I **= [average** ***d (I, j) j*** ***R splinter group]*** **- [average** ***d (I, j) j R*** **splinter group]**
3. Find an object **h** for which the difference D_h **is** the largest. If D_h **is** positive, then h is, on the average close to the splinter group.
4. Repeat **Steps 2** and 3 until all differences D_h are negative. The data set is then split into two clusters.
5. Select the cluster with the largest diameter. The diameter of a cluster is the largest dissimilarity between any two of its objects. Then divide this cluster, following steps 1-4.
6. Repeat **Step 5** until all clusters contain only a single object.

3.2 SILHOUETTES

A silhouette value S is expressed for each object as follows.

S= (b-a)/max(a,b)

Here, a particular object I **is** in cluster A and a is equal to the average dissimilarity of I **to** all other objects in A. For every other cluster not equal to A, cluster B has the smallest average dissimilarity between its objects and **I** which is equal to b. The cluster B is the nearest neighbor of objects **I**. 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.

4 Study Corridor and Data Collection Techniques

4.1 STUDY CORRIDORS

The commercial capital of India, Mumbai Metropolitan is considered for this study. The metropolitan has linear pattern of transport network having predominant North- South commuter movements. South Mumbai houses various work place so during morning time people move towards South for work and during evening hours they returns towards north to their homes in the Suburbs of Mumbai. So in this study five major corridors were chosen out of which four are north-south corridors and one is east-west corridor. The North-South corridors are 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 the only East-West corridor is Versova- Andheri- Ghatkopar- Vashi (VAGV) (Corridor-5). These five corridors are overlapped on the GIS base map of Greater Mumbai are shown in Fig.1.

4.2 DATA COLLECTION

The probe vehicle used in this research work is mid-sized cars. This vehicle was fitted with Trimble Geo-XT GPS receiver, so that it was adjusted to log speed data continuously (at time intervals of one second). The GPS data provides both spatial and time/distance based data from which various traffic parameters can be derived, including travel time, stopped time, travel speeds (instantaneous and average), and various congestion indices. In order to get unbiased data sets, we used three mid-sized cars and took the help of three drivers on different days of the survey work. The first type is roadway inventory details. In this survey 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. During the collection of inventory details proper segmentation technique was applied, which is the directional stretch of road section immediately after signalized intersections to the location point immediately after the next signal.

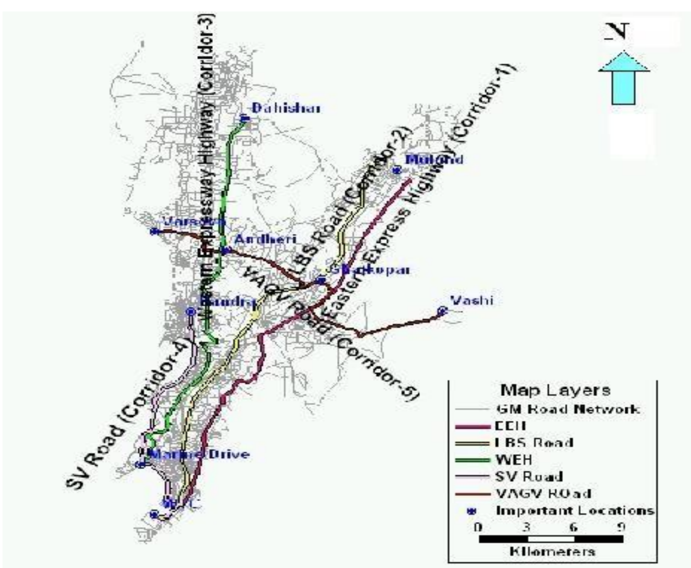

Fig.1 Map of Study Corridor (Mumbai)

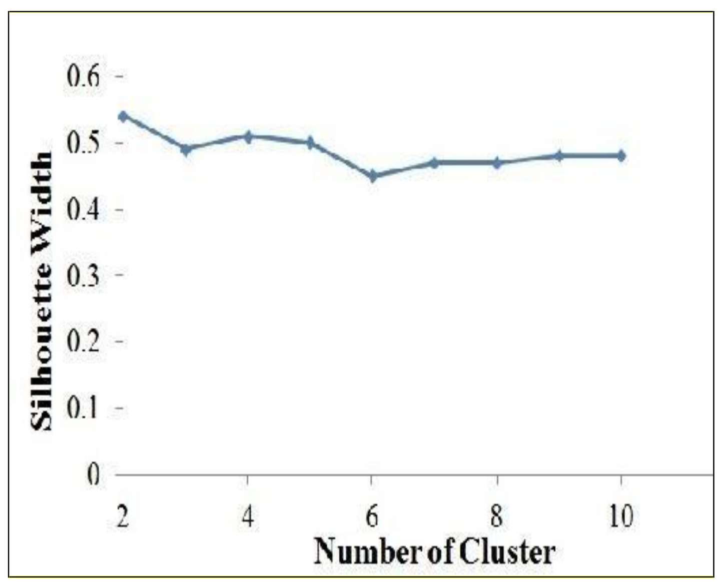

Fig.2 Validation of Number of Clusters.

The second type of survey conducted was to find free flow speed. Before going for the free flow speed data collection, the duration during which the traffic volume is less than or equal to 200 vehicles per lane per hour should be known. For that a detailed 24-hour traffic volume count survey was conducted prior to collection of FFS. The traffic volume data were collected on 45 stations on seven screen lines. From survey data traffic volume per lane per hour were calculated for roads comings under the study area. It was found that free flow traffic condition (less than 200veh/ln/hr.) is approaching at 12 mid-nights and all road sections are having free flow traffic conditions from 1 AM to 5 AM. Hence free flow speed for all these roads were collected using GPS receiver fitted on a probe vehicle during these hours. It is observed that the probe vehicle had maintained free flow speed between 40 km/hr. to 65 km/hr. on significant number of observed street segments and few segments had maintained free flow speed below 40km/hr. or above 65 km/hr. 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 version 3.00. The accuracy of field data was improved significantly using differential correction.

5 Result and Analysis

In the first step, free flow speed data were used in DIANA, and then input data (free flow speed) and output data (cluster centers) found from the analysis are used in computing validation parameters. The values of the Silhouette width obtained for 2 to 10 number of clusters are plotted in Fig.2. The value of Silhouette width is interpreted to obtain the optimum number of clusters in deciding the classification of street segments into number of Urban street classes. Lesser number of clusters is preferably adopted by considering the difference in silhouette width prior to that number of cluster; hence four numbers of clusters is preferred over five in this case. Hence, considering Silhouette width for different number of clusters, the optimal number of clusters was found to be 4. So it has been decided to categorize the urban streets into four classes based on free flow speeds on DIANA clustering. Thus free-flow speed ranges of urban street classes are defined in Indian context as shown in Fig. 3. It is observed from the collected data set that when a street segment falls under particular urban street class is agreed with the geometric and surrounding environmental condition of the road segments as well. From Fig. 3 it has been observed that FFS ranges of Urban Street IV is lesser compared to those values mentioned in HCM 2000. Large road network with a significant number of road segments are having varying road geometric characteristics and unplanned road side development compel vehicles to reduce the FFS to as low as 25 km/hr. Fig.3. DIANA classification of Urban Street Classes FFS on few road segments are significantly high; wide road with less road side development may help in attaining these speed limits. While substantial percentage of road segments are having FFS speed limits between 42- 70 km/hr.; which shows most of road segments are of average type and users get average quality of service. This signifies that road network need substantial improvement to provide better quality of service to the users. Direction-wise average travel speeds calculated on street segments are used on DIANA clustering to define speed ranges for LOS categories for each class. In Fig.4 (A-D) the speed values are shown by different symbols depending on to which LOS category they belong. The legend in Fig.4(A-D) gives the speed ranges for six LOS categories of urban street classes obtained by using DIANA clustering and speed ranges are shown in Table 1. From Table 1 it can be stated that free-flow speed ranges of urban street classes and speed ranges of LOS categories based on DIANA clustering in Indian context are significantly different from the suggested values applicable to western countries with homogeneous traffic flow condition. Highly heterogeneous traffic flows with substantial percentage of vehicles are having slow moving with large dimension compel normal traffic to reduce the speed hence result in lower speed ranges for LOS categories of urban streets. Also side friction developed due to commercial activity by roadside vendors, unwanted on-street parking, haphazard pedestrian activity coupled with random movements of street dogs etc. causes this reduction in speed limit of LOS categories. Fig.5 shows Silhouettes plot for urban street classes using free flow speeds. From this figure it is found that thickness of silhouettes of Urban Street class II (shown as 2) and IV (shown as 4) are comparatively high which means large numbers of street segments are falling under urban street class II and IV. Also it is found that Silhouette width of data points under urban street classes I to IV lies between 0.47 and 0.58. This indicates that free-flow speed data points form reasonably bonded within each urban street class. Also it is found that speed data points are well bonded within each level of service categories using silhouette validation parameter. Speed ranges for level of service categories (A-F) expressed in percentage of free-flow speeds were found to be 89, 72-89, 53-72, 40-53, 25 and 20-25 respectively in the present study. Whereas, in HCM (2010) it has been mentioned these values are 85 and above, 67-85, 50-67, 40-50, 30-40 and 30 and less percent respectively.

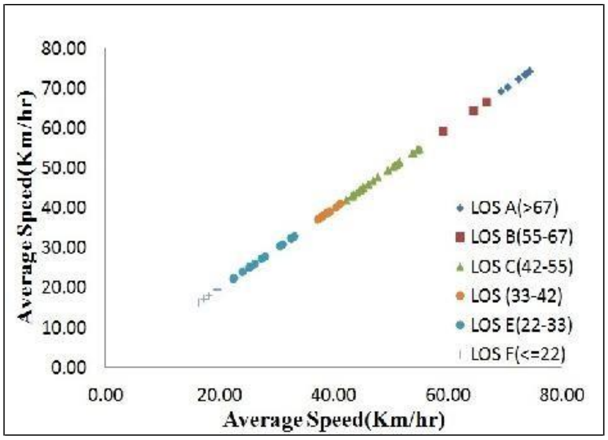

Fig.4 (A). LOS Categories of Urban Street Class I

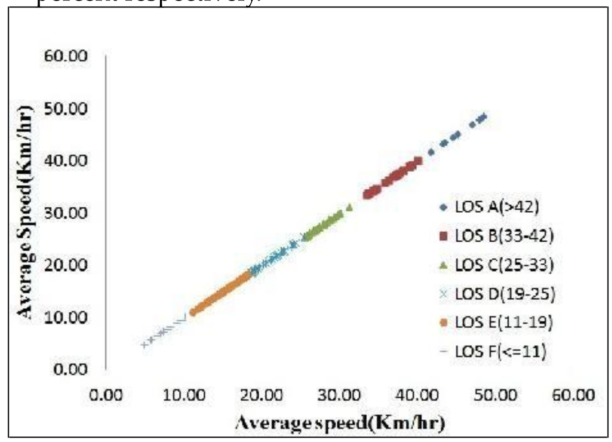

Fig.4 (B). LOS Categories of Urban Street Class II

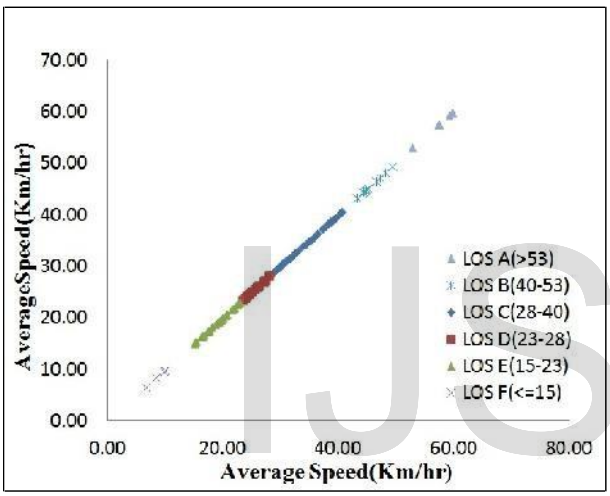

Fig.4 (C). LOS Categories of Urban Street Class III

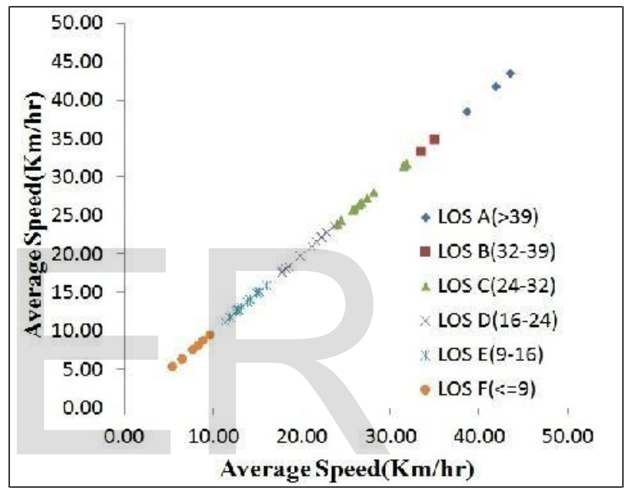

Fig.4 (D). LOS Categories of Urban Street Class IV

Silhouette Plot of FFS for n=100

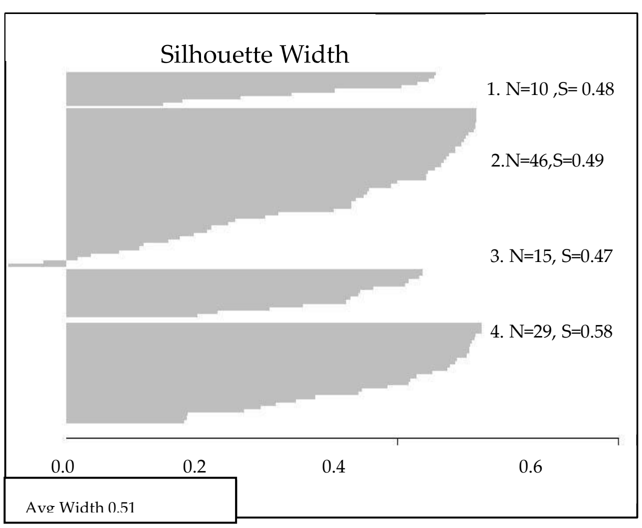

Fig.5. Silhouette Plot of FFS by DIANA Clustering.

LOS Categories of Different Classes of Urban Street

Urban Street Class	I	II	III	IV
Range of FFS (Mph)	93 - 70	70 - 55	55 - 42	42 - 25
Typical FFS (Mph)	75	60	50	40
LOS	Speed Km/hr.	Speed Km/hr.	Speed Km/hr.	Speed Km/hr.
A	>67	>53	>42	>39
B	>55-67	>40-53	>33-42	>32-39
C	>42-55	>28-40	>25-33	>24-32
D	>33-42.	>23-28	>19-25	>16-24
E	>22-33	>15-23	>11-19	>9-16
F	≤22	≤15	≤11	≤9

Table:1

6 Summary and Conclusion

In this research an attempt is made to define the LOS criteria of urban street of developing courtiers like India having heterogeneous traffic flow condition. From literature review it is known that GPS is an efficient tool for collecting large amount of speed data. Silhouette width was used as the validation parameters for the optimal number of cluster using FFS data for the classification of urban streets into number of classes. DIANA clustering algorithm was used on the collected speed data for two times for the classification of the data set into number of groups. Finally, the classification of Urban Street was done and LOS was defined.

Considering the geometric and surrounding environmental characteristics it is well convinced to classify various urban street segments into four classes in Indian context. Hence, agreed with the classification of street segments into four classes as mentioned in HCM 2000. From this study it was found that the free flow speed ranges of Urban Street Class-I to Urban Street Class-III is within the range defined by HCM 2000 but Class-IV is significantly lower than that mentioned in HCM 2000 because heterogeneous traffic flow and roads having varying geometric and surrounding characteristics. The speed ranges of levels of service categories under all the four urban street classes are found to be varying compared to the values mentioned in HCM 2000 because of substantial percentage of vehicles travelling on roads are slow moving. The high value of v/c ratio makes the roads less available for high speed movement of vehicles. Unwanted movement of pedestrians along and across the road sections creates a side friction and compelled travelers to reduce vehicular speed. A large number of Road side vendors and on-street parking occupy substantial portion of road sections result in high v/c ratio. With the application of GPS, a large amount of speed data was able to collected at a very short time period which are of course very accurate also. Hence this tool can be applied to collect speed data and cluster analysis can be applied to define the speed ranges for various countries to define the levels of service of their own rather than following some values which are not very much appropriate for them. In the developing countries like India, there is heterogeneous traffic flow the LOS definition makes significant role in improving traffic facilities. LOS criteria for an urban street may also be implemented to define speed ranges of Urban Street having similar geometric and environmental condition.

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