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A Review on Level of Service Analysis of Urban Streets

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ABSTRACT *The paper presents a classification and analysis of the results achieved using various tools for the estimation of level of service (LOS) of urban streets. The basic premise of urban streets and LOS are discussed. LOS is analyzed quantitatively and qualitatively. Average travel speed (ATS) on street segments is considered as the measure of effectiveness in defining LOS criteria of an urban street using quantitative methods. The travel speed data collection procedure has been changing over time from the traditional followed moving observer method to a distance measuring instrument and now global positioning system is being extensively used worldwide. Classifying urban streets into number of classes and ATSs on street segments into number of LOS categories are essential components of LOS analysis. Emphasis is put on application of soft computing techniques such as fuzzy set theory, genetic algorithm, neural network, cluster analysis and modeling and simulation for the LOS analysis of urban streets both quantitatively and qualitatively. Quality of service of urban streets is analyzed using the satisfaction level that the road user perceived while using the urban road infrastructure. Possibilities are shown regarding the further improvement in research methodology.*

1. Introduction

The level of service (LOS) concept for highways was first introduced in the 1965 version of the highway capacity manual (HCM, 1965). After its introduction, there were a large number of studies on measuring LOS, as a way to evaluate the quality of road service as perceived by users. In this version of the manual, LOS was described by six classes from 'A' to 'F' which represents a range of operating conditions with the definition based on the combination of travel time and the ratio of traffic flow rate to the capacity of road sections. This concept was redefined in relation to several traffic conditions in the 1985 version of the HCM (1985). The measures of LOS adopted in the HCM (1985) include travel speed, traffic flow rate, and traffic density, for each type of road. The LOS is defined as "a qualitative measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, comfort and convenience" in the 2000 version of HCM (2000). According to HCM (2000), LOS is a quantitative stratification of performance measures or measures that represent quality of service (QOS) designated six

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LOS for each type of facility, from 'A' to 'F', with LOS 'A' representing the best operating conditions and LOS 'F' the worst. However, according to 2010 version of HCM (2010), there are many ways to measure the performance of a transportation facility or service and many points of view that can be considered in deciding which measurements to make. The agency operating a roadway, automobile drivers, pedestrians, bicyclists, bus passengers, decision-makers, and the community at large all have their own perspectives on how a roadway or service should perform and what constitutes 'good' performance. As a result, there is no one right way to measure and interpret performance. Since its introduction from 1965 to 2010 version of HCM, classes (A–F) of LOS remain unchanged, however different factors have been considered to define LOS. HCM (1965) considered travel time and traffic flow (v) to capacity (c) ratio are the major factors affecting LOS. Traffic flow and two more fundamental parameters such as travel speed and traffic density have been emphasized in defining LOS categories in HCM (1985). In HCM (2000), due considerations has been given to the factors such as travel time and travel speed which were considered in the earlier two versions. Apart from these two parameters user's freedom to maneuver, comfort and convenience and interruption from traffic while travels on roads have been considered. While in HCM (2010), no emphasis has been given to a particular measure of effectiveness (MOE) as considered in the earlier versions and kept it open for the users to decide based on their own assessment through qualitative measures.

LOS is defined by one or more service measures that reflect the traveler perspective on transportation system operation and several alternatives have been suggested for improving the scaling of LOS. For example, the studies of Baumgaertner (1996), Cameron (1996) and Brilon (2000) all provided some insight into the limitations of the HCM (1985) LOS measures. Baumgaertner (1996) pointed out that the continuous growth of urban populations, vehicle ownership, average trip length, and number of trips has resulted in a significant increase in traffic volumes. Thus, travel conditions that would have been viewed as intolerable in the 1960s are considered normal by today's motorists, especially commuters. Cameron (1996) stated that it was not uncommon to wait three minutes at a congested urban intersection with average delays often exceeding two minutes. Among the approaches suggested by these studies, expanding the six LOS designations to nine or more in an attempt to better describe traffic conditions was a common theme. Kittelson and Roess (2001) have noted down that the HCM (2000) methodologies have not been based upon user perception surveys. Users consider a wide variety of factors that influences the perception of QOS it perceived. Factors range from elements related to traffic operations (e.g. signal timing), roadway geometry (e.g. lane width), esthetic aspects (e.g. presence of trees), sign visibility, and other road users. The HCM (2000) methodologies have resulted from a combination of consulting studies, research, debates and discussions of the Highway Capacity and QOS (HCQS) committee (Pecheux, Pietrucha, & Jovanis, 2000). In July 2001, at the mid-year meeting of the HCQS committee, a motion was passed that stated "The Committee recognizes that there are significant issues with the current LOS structure and encourages investigations to address these issues" (Pecheux, Flannery, Wochinger, Lappin, & Rephlo, 2004). Flannery, Wochinger, and Martin (2005) while relating quantitative to qualitative service measuring methods for urban streets found that LOS calculated by HCM (2000) methodology, predicted 35% of the variance in mean driver rating. Brilon and Estel (2010) have presented standardized methods that allow a differentiated evaluation of saturated flow (LOS 'F') conditions beyond a static consideration of traffic conditions in German HCM.

Defining LOS criteria is basically a classification problem and cluster analysis is a suitable technique that can be applied for the solution of it. For this cluster analysis, a large amount of free flow speed (FFS) and average travel speed (ATS) data are required because LOS of urban street is a function of travel speed and functional and geometric characteristics of street segments. Traditionally travel speed data are collected using the floating car method. Turner, Eisele, Benz, and Holdener (1998) found that the floating car method was susceptible to human error. With improvement in computers, the distance measuring instrument (DMI) came as the solution of the floating car method. However, Benz and Ogden (1996) found a limitation in this method relating to installation of the DMI unit and data storage problems. Though speed ranges are not well defined for LOS categories, limited studies have been carried out for heterogeneous traffic flow in Indian context. It has been suggested by the 1990 version of the Indian Road Congress (IRC, 1990) that on urban roads, the LOS are strongly affected by factors such as heterogeneity of traffic, speed regulations, frequency of intersections, presence of bus stops, on-street parking, roadside commercial activities, and pedestrian volumes, etc. Maitra, Sikdar, and Dhingra (1999) redefined the LOS boundaries into nine groups 'A' to 'I' by quantifying congestion as MOE for heterogeneous traffic flow on urban roads. In another study, Marwah and Singh (2000) have attempted to classify LOS categories based on simulation results of benchmark roads and traffic composition and the LOS were classified into four groups (I–IV).With the advancement of technologies, the global positioning system (GPS) has been successfully applied to data collection and geographic information system (GIS) have extensively used for data compilation. Taking advantages of these technologies, Bhuyan and Rao (2010, 2011, 2012) have used GPS and various clustering methods such as fuzzy-C means (FCM), hierarchical agglomerative clustering (HAC), *k*-means and *k*-medoid clustering to classify urban streets into a number of classes and ATS on segments into number of LOS categories. In these studies, ATS on street segments was used as the MOE, which has been obtained from second-wise speed data collected using GPS receiver. The authors have employed several cluster validation measures for the classification of urban streets into number of classes at its context. From these studies authors have found that FFS ranges of urban street classes and speed ranges of LOS categories valid in Indian context are different from those values specified in HCM (2000).

A method for evaluating the multimodal LOS (MMLOS) provided by different urban street designs and operations was developed and calibrated by Dowling et al. (2008a) as published in the NCHRP report 616 of the Transport Research Board. This MMLOS method is designed for evaluating 'complete streets', context-sensitive design alternatives, and smart growth from the perspective of all users of street. The MMLOS method estimates the auto, bus, bicycle, and pedestrian LOS on urban streets. The data requirements of the MMLOS method included geometric cross-section, signal timing, the posted speed limit, bus headways, traffic volumes, transit patronage, and pedestrian volumes. Researchers across the world are involved in various studies for LOS analysis of urban streets is summarized in Table 1.

Table 1. LOS analysis of urban streets

Item/application of techniques	Authors (publication year)	Item/application of techniques	Authors (publication year)
Introduction	HCM (1965)	Cluster analysis	Laviolette, Seaman, Barrett, and Woodall (1995)
			Prassas, Roess, and Mcshane (1996)
	HCM (1985)		Lingras (2001)
			Cheol and Stephen (2002)
			Fang and Pecheux (2009)
	IRC (1990)		Azimi and Zhang (2010)
	Baumgaertner (1996)		Deshpande, Nathan, and Marguerite (2010)
	Cameron (1996)		Ivana, Zvonko, and Marjana (2011)
			Mohapatra, Bhuyan, and Krishna Rao (2012)
	Benz and Ogden (1996)	Modeling	Madanat, Cassidy, and Ibrahim (1994)
	Turner et al. (1998)		Dixon (1996)
	Maitra et al. (1999)		Guttenplan, Landis, Crider, and McLeod (2001)
	Brilon (2000)		Landis et al. (2003)
	HCM (2000)		Ballis (2004)
	Pecheux et al. (2000)		Dowling et al. (2008b)
	Marwah and Sing (2000)		Roess, Vandehey, and Kittelson (2010)
	Kittelson and Roess (2001)	Simulation	Lin and Su (1994)
	Pecheux et al. (2004)		Klodzinsk and Al-Deek (2002)
	Flannery et al. (2005), Dowling et al. (2008a)		Arasan and Vedagiri (2010)
	Brilon and Estel (2010)	QOS	Kita and Fujiwara (1995)
	Bhuyan and Rao (2010)		Pursula and Minnaweurlander (1999)
			Dowling, McLeod, Guttenplan, and Zegeer (2002)
	HCM (2010)		Chu and Baltes (2003)
	Bhuyan and Rao (2011)		Pecheux, Pietrucha, and Jovanis (2003)
	Bhuyan and Rao (2012)		Pecheux et al. (2004)
Fuzzy set theory	Zadeh (1965)		Flannery et al. (2005)
	Chakroborthy and Kikuchi (1990)		Xin, Fu, and Saccomanno (2005)
	Ndoh and Ashford (1994)		Zolnik and Cromley (2006)
	Pattnaik and Kumar (1996)		Romana and Perez (2006)
			Petritsch et al. (2006)
			Tan, Wang, Lu, and Bian (2007)
	Lee, Kim, and Pietrucha (2007)		Dandan, Wei, Jian, and Yang (2007)
	Shao and Sun (2010)		Muraleetharan and Hagiwara (2007)
ANN	Lingras (1995)		Jensen and Trafitec (2007)
	Xu, Wong, Yang, and Tong (1999)		Jensen (2007)
	Basu, Maitra Roy, and Maitra. (2006)		Zegeer, Blogg, Nguyen, and Vandehey (2008)
			Flannery, Rouphail, and Reinke (2008)
	Chen, Li, Ma, and Shao (2009)		Clark (2008)
			Shouhua, Zhenzhou, Chiqing, and Li (2009)
Uncertainty and reliability analysis	Spring (1999)		Ko, Washburn, and McLeod (2009)
	Kikuchi and Chakroborty (2006)		Cao, Yuan, Li, Hu, and Johnson (2009)
	Margiotta and Taylor (2006a)		Ma, Yan, Huang, and Abdel-Aty (2009)
	Margiotta and Taylor (2006a)		Galicia, Rajbhandari, Cheu, and Aldrete (2011)
			Hensher and Li (2012)

2. Urban Streets and LOS Concepts

In the hierarchy of street transportation facilities, urban streets (including arterial and collectors) are ranked between local streets and multilane suburban and rural highways. The difference is determined principally by street function, control conditions, and the character and intensity of roadside development. Arterial streets are roads that primarily serve longer through trips. However, providing access to abutting commercial and residential land uses is also an important function of arterials. Collector streets provide both land access and traffic circulation within residential, commercial, and industrial areas. Urban Street LOS is based on the average through-vehicle (vehicles passing directly through a street segment and not turning) travel speed for the segment or for the entire street under consideration. Travel speed is the basic service measure for urban streets. The ATS is computed from the running times on the urban street and the control delay of through movements at signalized intersections. The control delay is the portion of the total delay for a vehicle approaching and entering a signalized intersection that is attributable to traffic signal operation. Control delay includes the delays of initial deceleration, move-up time in the queue, stops, and re- acceleration. The LOS for urban streets is influenced both by the number of signals per kilometer and by the intersection control delay. Inappropriate signal timing, poor progression, and increasing traffic flow can degrade the LOS substantially. Streets with medium-to-high signal densities (i.e. more than one signal per kilometer are more susceptible to these factors, and poor LOS might be observed even before significant problems occur. On the other hand, longer urban street segments comprising heavily loaded intersections can provide reasonably good LOS, although an individual signalized intersection might be operating at a lower level.

Four urban street classes are defined in HCM (2000). The classes are designated by number (i.e. I, II, III, and IV) and reflect unique combinations of street function and design. The functional component is separated into two categories: principal arterial and minor arterial. The design component is separated into four categories: high-speed, suburban, intermediate, and urban. A common application of the LOS analysis is to compute the LOS of a current or changed facility for the near term or distance future. The objective of an urban street LOS analysis at a planning level is to estimate the operating conditions of the facility. An important use for this type of analysis is to address growth management.

3. Application of Various Techniques for LOS Analysis

3.1 *Fuzzy Set Theory*

Some studies that have been carried out using fuzzy set theory for LOS analysis are reviewed. Fuzzy set theory was introduced by Zadeh (1965) as a general approach to express the different types of uncertainty in human systems. Chakroborthy and Kikuchi (1990) have discussed the application of fuzzy set theory to the analysis of highway capacity and LOS. In this study, fuzzy numbers were used to represent the values of input variables and output variables which were involved in calculating capacity and service level. The authors have shown the limitations of the LOS analysis procedure to determine highway capacity and service level. In this research, it has been mentioned that HCM (1985) suggests the use of one criterion for determining the LOS that can represent the combined effect of all the influencing factors of the quality of traffic flow. Determining the LOS based on one criterion could exclude many qualitative aspects of traffic flow which influence the LOS. Second, specific LOS (A–F) is defined based on rigid ranges of values for the criterion. LOS is a qualitative measure of traffic flow and, thus the boundary between two levels of service cannot be determined clearly. For example, in the HCM (1985) volume to capacity ratio *v/c* is used as the criterion for determining the LOS of a basic freeway segment. A *v/c* of .54 represents a LOS (B), it is therefore logical to assume that a *v/c* of .55 which indicates a LOS (C) would not depict a very different situation while by definition, has quite different service characteristics from that of LOS (B). This suggests that the current method may not be suitable as an indicator of the criterion lies at the boundary of two LOS categories. If the two sets are made intersecting, then it is possible for a condition to belong to both LOS (B) and LOS (C). If the boundary of two adjacent sets is not rigid, but somewhat flexible, then a given condition can belong to more than one LOS category with a varying degree. This can be accommodated by defining each LOS category as a fuzzy set.

Ndoh and Ashford (1994) have developed a model to evaluate airport passenger services using fuzzy set theory. The authors pointed out the hierarchical structure of the service system and proposed that LOS be decomposed into its component service attributes (information, waiting time at processing activities, availability of seats, etc.). Each component service attribute can be assigned a linguist variable name (high, medium, etc.). The methodology proposed by the authors is certainly quite compactible with the way passengers perceive transport services. In their words, the authors have stated, "The literature on transportation LOS evaluation indicates a strong impetus to move away from a strictly capacity/volume or time/space-based measure to one that directly incorporates the perception of passengers." In a similar kind of study, Pattnaik and Kumar (1996) have used fuzzy set theory and user's perception to define LOS of urban roads in Indian environment. Lee et al. (2007) developed a method to evaluate transportation service quality using a fuzzy aggregation and a cultural consensus analysis technique. In applying the developed method to assess the service quality of signalized intersections, six analysis criteria were selected. Using a fuzzy weighted average technique on six criteria, individual perceptions regarding the service qualities of signalized intersections were evaluated. Shao and Sun (2010) proposed a concept of categorization of LOS into two parts: Level of facility supply and Level of traffic operation. Travel speed to FFS ratio was considered as evaluation index of traffic operation. The fuzzy set was used by authors to categorize traffic operation into different groups. So the authors have 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.

3.2 *Artificial Neural Network*

Artificial neural networks (ANNs) is the result of academic investigations that use mathematical formulations to model nervous system operations. The resulting techniques are being successfully applied in a variety of everyday business application. ANN is used to learn pattern and relationship in data. Lingras (1995) compared the grouping of traffic patterns using the HAC and the Kohonen neural network methods in classifying traffic patterns. It has been mentioned that the Kohonen neural network integrates the hierarchical grouping of complete patterns and the least-mean-square approach for classifying incomplete patterns. Such an approach is useful in using hour-to-hour and day-to-day traffic variations in addition to the monthly traffic-volume variation in classifying highway sections. 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. Basu et al. (2006) modeled passenger car equivalency for urban mid-block using stream speed as a measure of equivalence. In this study, a neural network approach was explored to capture the effects of traffic volume and its composition level on the stream speed. Chen et al. (2009) 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.

3.3 *Cluster Analysis*

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. Defining LOS criteria is basically a classification problem and cluster analysis is the most suitable technique that can be applied for the solution of it. Laviolette et al. (1995) along with a number of discussants compared fuzzy and probabilistic approaches in general, and among these contributions is a discussion of fuzzy cluster analysis. The connection between fuzzy logic and fuzzy cluster analysis is usually only through the application of membership functions, and not the more comprehensive theory. Prassas et al. (1996) applied the cluster analysis tools to a set of traffic engineering data on which deterministic modeling and regression analysis have been applied before. From this study, the authors have concluded that cluster analysis is a powerful exploratory technique and helps in identifying several distinct modalities within the traffic data. Lingras (2001) applied HAC technique and an evolutionary genetic algorithms (GAs) approach for classifying highway sections. It has been pointed out that hierarchical approach tends to move farther away from the optimal solution for a smaller number of groups, however GAs-based approach provides better results when the number of groups is relatively small. To meet the user requirements of the advanced traffic management and information system, Cheol and Stephen (2002) have demonstrated a technique for the development of real-time intersection LOS criteria. In this study, the authors have used a new MOE, which they called re-identification delay at signalized intersections. The authors have applied several cluster analysis methods including *k*-means, fuzzy and self-organizing map for the derivation of LOS categories. The procedures used in this study were readily transferable to other signalized intersections for the derivation of real-time LOS. Fang and Pecheux (2009) studied LOS of signalized intersections taking user perception and FCM clustering into account to get a distinct cluster of user perceived delay and service rating. The clustering result was analyzed according to approach membership, delay membership and rating membership. Azimi and Zhang (2010) have applied three pattern recognition methods (*k*-means, FCM, 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. Deshpande et al. (2010) have determined the LOS on an urban street in a more systematic and accurate manner. This was based on urban street classification and ATS on the arterial. A state-of-the-art hybrid algorithm was developed by Ivana et al. (2011) to classify urban roads based on vehicle track and infrastructural data collected through GPS. Mohapatra et al. (2012) applied GA Fuzzy clustering on speed data collected using GPS to define FFS ranges of urban street classes and speed ranges of LOS categories of urban streets. In this study, a number of cluster validation parameters such as C-index, Weighted inter−intra index, Hartigan index, R^2 index, Krzanowski−Lai index are used on FFS data to find the optimal number of clusters required to justify the classification of street segments into number of classes.

Bhuyan and Rao (2011) applied the HAC method to classify FFS data into number of street classes. In this study, the classification procedure has been explained through an example. The following three steps were followed to perform HAC on FFS data using the statistics toolbox in MATLAB to classify urban streets into classes.

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 $X = [\text{ffs1};\ \text{ffs2};\ \text{ffs3};\ \text{ffs4};\ \text{ffs5};\ \text{ffs6}] = [85.00;\ 92.56;\ 72.85;\ 50.66;\ 39.89;\ 38.58]$. While applying HAC, the distance function calculates the distance between ffs1 and ffs2, ffs1 and ffs3, 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.

$$\begin{aligned} Y = [&\text{ffs1}-2 \quad \text{ffs1}-3 \quad \text{ffs1}-4 \quad \text{ffs1}-5 \quad \text{ffs1}-6 \\ &\text{ffs2}-3 \quad \text{ffs2}-4 \quad \text{ffs2}-5 \quad \text{ffs2}-6 \quad \text{ffs3}-4 \quad \text{ffs3}-5 \quad \text{ffs3}-6 \\ &\text{ffs4}-5 \quad \text{ffs4}-6 \quad \text{ffs5}-6] \\ = [&7.56 \quad 12.15 \quad 34.34 \quad 45.11 \quad 46.42 \quad 19.71 \quad 41.90 \quad 52.67 \quad 53.98 \\ &22.19 \quad 32.96 \quad 34.27 \quad 10.77 \quad 12.08 \quad 1.31]. \end{aligned}$$

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.

$$Z = \begin{bmatrix} 5 & 6 & 1.31 \\ 1 & 2 & 7.56 \\ 4 & 7 & 10.77 \\ 3 & 8 & 12.15 \\ 9 & 10 & 22.19 \end{bmatrix}$$

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. 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. Similarly, object 8 is the cluster formed by grouping objects 1 and 2. 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.

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 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).

3.4 *Uncertainty and Reliability Analysis*

Uncertainty and reliability analysis techniques can be applied to the prediction of various fundamental parameters of traffic operations on urban streets. By directly

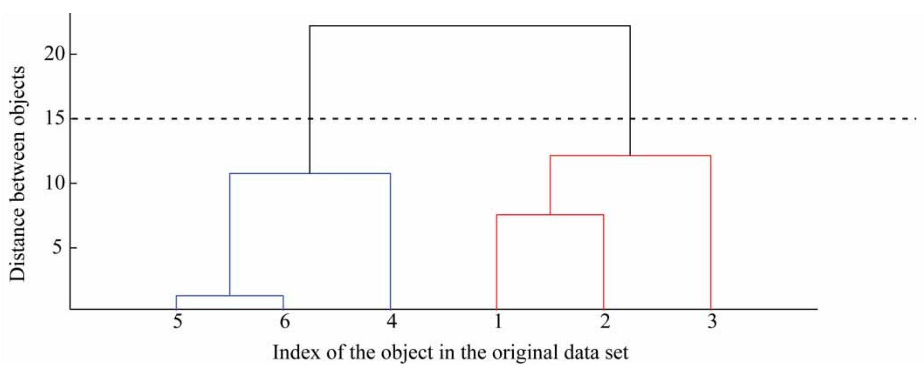

Figure 1. Typical dendrogram using sample FFSs data.
Source: Bhuyan and Rao (2011).

targeting the source of unreliable delay through urban street operations, the chances of unexpected and extreme delay are greatly reduced, enabling travelers to experience more consistent conditions from day to day. The recent emphasis on improving LOS analysis reliability points to increased use of operational strategies. Spring (1999) stated that the use of distinct boundaries or thresholds limits the subjective and continuous characteristics of the QOS. An inherent weakness in this step-function approach is that the use of distinct boundaries of a sole measure, limits the accuracy with which a facility may be characterized as it does not provide access to the linguistic uncertainty and subjective nature associated with LOS. 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 LOS categories. In their two separate studies, Margiotta and Taylor (2006b, 2006c) tried to make relation between the traffic congestion level with travel time prediction and distributing the information to the users after reliability analysis. In this study, a new initiative has been taken by the authors in developing a connection between LOS and reliability.

3.5 *Modeling*

Researcher and transportation planners have been attempted to predict the LOS that the urban road infrastructure provides to road users. This LOS concept has been changing over a time period from an individual mode to multi-mode, from segment analysis to corridor analysis, from regression analysis to discrete choice analysis for the application in planning, design and operation analysis of transportation system. Madanat et al. (1994) have applied the ordered Probit model to find threshold values for each LOS categories using user perceptions. Dixon (1996) developed the Gainesville mobility plan prototype as the congestion management system plan for Gainesville, Florida, and incorporated LOS performance measures for bicycle and pedestrian facilities. The Gainesville bicycle and pedestrian LOS performance measures used a point scale resulting in an LOS rating system of A–F. The methodology hypothesizes that there is a critical mass of variables that must be present to attract non-motorized trips. The methodology is applicable for corridor evaluations on arterial and collector roadways in urban or suburban areas. Guttenplan et al. (2001) presented methods of determining the LOS to scheduled fixed-route bus users, pedestrians, and bicyclists on arterials and through-vehicles. This was a comprehensive approach for LOS of individual modes conducted for arterial roads in Florida. Landis et al. (2003) have developed corridor- and facilities-level LOS methodologies. For this, the authors have developed the methodology for LOS analysis of intersections using through movement of bicycles. The intersection LOS model for the bicycle through movement was based on Pearson correlation analyses and stepwise regression modeling of approximately 1000 combined real-time perceptions from bicyclists traveling a course through a typical US metropolitan area's signalized intersections. Ballis (2004) introduced a set of LOS standards to provide reference values for investment strategies and terminal design. This set of standards was also useful for the interpretation of directives at the policy level and to quantified guidelines at the planning level. Dowling et al. (2008b) have developed a methodology for the assessment of the QOS provided by urban streets for the flow of traffic by various modes on the road network at the 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. Roess et al. (2010) 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.

3.6 *Simulation*

Traffic simulation is the mathematical modeling through the application of computer software to better help plan, design and operates transportation systems. Simulation of transportation system started over 40 years ago. Several researches have been carried to simulate the traffic for the analysis of LOS of urban transportation system. Lin and Su (1994) have developed a methodology to determine LOS for main-line toll plaza. That methodology relies heavily on a computer simulation model referred as toll-plaza simulation model (TPSIM). The reliance on computer simulation reflects recognition of the limitations of analytical model, popularity and computing power of personal computer. A good macroscopic methodology for evaluating and measuring the LOS at a toll plaza was determined by Klodzinski and Al-Deek (2002). On the basis of field research and data analyses, the 85th percentile of the cumulative individual vehicular delay was found to be the most comprehensive measure for evaluating the LOS at a toll plaza. TPSIM was used to produce varied percentages of electronic toll collection usage and plaza configurations. An LOS hierarchy was established based on the conclusions of this analysis and referred to the HCM (2000). Arasan and Vedagiri (2010) through computer simulation studied the effect of a dedicated bus lane on the LOS of heterogeneous traffic condition in Indian context. The author also estimated the probable modal shift by the commuter when a dedicated bus lane is introduced.

3.7 *Quality of Service*

While citing limitations of the quantitative method of LOS analysis Kita and Fujiwara (1995) mentioned that quantitative measures of the LOS are not the LOS itself, but merely characteristics of traffic conditions which have rather a strong relationship to the LOS of the traffic, and not necessarily shows the QOS perceived by the drivers. Different measures used for roads or road sections of different types make it impossible to evaluate and compare the LOS between the road sections of different types. This inconvenience is due to using such traffic characteristics as substitution measures. Pursula and Minnaweurlander (1999) have described a combined revealed preference (RP) and stated preference (SP) survey that was done in the Helsinki, Finland, metropolitan area to reveal the importance of different LOS factors in public transportation. The RP and SP data were analyzed together using structured-tree-type logit models to adjust the variances in different data sets. The results of the survey were quite in line with other similar studies reported in the literature and give an estimate of the passenger response to the public transportation LOS attributes included in the study. Dowling et al. (2002) have developed a methodology by the combination of the Transit Capacity and QOS Manual (TCQSM) and the HCM (2000), which represented a significant advance in the direction of MMLOS analysis. Four classes of corridors were recommended, and the methodology was tested on two classes of urban corridors, with and without a freeway. The methodology was applied in three steps: (a) corridor definition, (b) computation of modal LOS, and (c) reporting of results. The methodology was applied to six case studies throughout Florida at generalized and conceptual planning levels.

Chu and Baltes (2003) have developed a statistically estimated model of pedestrian QOS for mid-block street crossings as part of its multimodal QOS program. This model was to be used in evaluating the LOS of street segments for pedestrian street crossing. A process was used to select potential determinants of perceived pedestrian QOS for mid-block street crossings. This process was structured and involves two steps. The first step involves the selection of a set of potential determinants through a theoretical analysis of pedestrian behavior for street crossing. The second step involves narrowing down this theoretical set through a practical analysis of planning needs and data requirements by an advisory committee. Pecheux et al. (2003) presented the results of a qualitative study of driver perception of QOS on urban arterial streets. The purpose of the study was to identify the factors that are important to drivers of personal automobiles (non-commercial) regarding the quality of their driving experience. The study used an in-vehicle, on-the-road methodology in which drivers drove their own vehicles and talked out loud about the driving experience. The data from the drivers and the surveys were summarized and categorized into 'QOS factors' and 'driver needs'. The authors have used a video laboratory approach to investigate driver perception of LOS at signalized intersections and found at least 15 factors that influenced driver's QOS ratings. The results from this study showed a need for efficient traffic flow (an inverse of delay), and volume/congestion and presence of large vehicles factors. Pecheux et al. (2004) have used an in-vehicle field approach to determine the factors that affect automobile drivers' perceptions of service quality on urban streets. The objectives of this study were to (a) develop and test a methodology to obtain driver's opinions with regard to urban street QOS, (b) apply the methodology to identify the factors that affect driver's perceptions of QOS on urban streets, and (c) provide a qualitative foundation for the development of quantitative QOS tools that are based on the perceptions of drivers. The authors believed that by identifying a wide range of factors that influence driver's perceptions of service quality on urban streets, this study has increased the knowledge and understanding of the needs and values of automobile drivers on urban streets and has laid the groundwork for future studies aimed at developing quantitative QOS tools and models.

Flannery et al. (2005) presented the results of a study that compared driver assessment of performance of urban streets to objective measures of performance, including LOS. The authors have conducted a mean driver rating study to test the ability of the driver perception of service quality to predict LOS. The study found that the LOS did not completely represent driver assessment of performance because drivers perceived quality of urban street segments in several dimensions, including travel efficiency, sense of safety, and esthetics. The authors attempted to compare the QOS 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 esthetics (the presence of trees). Xin et al. (2005) have described a case study of applying transit LOS analysis methodology in the most recent edition of the TCQSM to evaluate the quality of transit service on several travel corridors in an urbanized area. The authors focused on four LOS measures: service frequency, hours of service, service coverage, and transit-auto travel time. From this study, it has been observed that the TCQSM methodology for evaluating the LOS of a transit system is straightforward and relatively easy to apply and it covers the important aspects of QOS concerns by passengers, transit operators, and planners. But this case study has revealed several critical issues such as; the TCQSM adopts the approach of using multiple LOS measures to depict the QOS of a transit system, an approach that somehow departs from the HCM philosophy of using no more than two factors to decide the LOS of a highway facility. Secondly, in the case of using the existing methodology to assess the LOS of a travel corridor, the results of such analysis depend to a large extent on how the activity centers are defined, because each activity center is represented by a single point (centroid), and all trips are assumed to begin and end at the centroid. The results could, therefore, be quite different from reality. Thirdly, in the service coverage LOS (SC-LOS) analysis, TCQSM methodology assumes that only those users who are located within a fixed walking distance from transit stops would use transit service. Past studies, however, have indicated that a number of transit users are willing to walk longer distances to use transit services. Therefore, that assumption may lead to underestimation of the service coverage in a given area. The fourth critical issue in the travel time LOS analysis, the TCQSM assumes that passengers consider different travel time components (walking, waiting, and in-vehicle) to have same importance. In reality, however, passenger perception on different travel time components is quite different. And the travel time difference measure is expressed by the absolute transit-auto travel time difference and ignores trip length. As a result, that measure in some degree cannot provide a reasonable explanation on users' behaviors and perception. Recently, Hensher and Li (2012) have studied bus rapid transit (BRT) systems using the data collected from 15 countries. In this study, a number of sources of systematic variation are identified which have a statistically significant impact on daily passenger trip numbers. These sources include: price sensitivity, frequency of service, capacity of BRT system, connectivity, integration with other modes of public transportation, equipment (pre-board fare collection system) and quality control to ensure the service level.

Zolnik and Cromley (2006) have developed a bicycle LOS methodology for urban and suburban as well as for rural road segments, using the bicycle-motor vehicle collision frequency and severity in the GIS environment. This study incorporates mental as well as physical stressors of bicyclists where collisions occurred to assess bicycle LOS for the regional road network. Romana and Perez (2006) have used a threshold speed to assess LOS for heavy traffic under platooning condition. In this study, the definition of threshold speed used by the authors "the minimum speed users consider acceptable in traveling on a uniform road section under heavy flows and platooning traffic". The method used the same MOE proposed by HCM, one reflecting percent time spent following (PTSF) and the second reflecting speed. However, it has been suggested that a threshold speed would be used to decide which MOE governs LOS in each period: if 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. Petritsch et al. (2006) have documented a study sponsored by the Florida Department of Transportation to develop a LOS model that represents pedestrians' perceptions of how well urban arterials with sidewalks (a combination of roadway segments and intersections) meet their needs. This pedestrian LOS model for roadway facilities was based on Pearson correlation analyses and stepwise regression modeling of about 500 combined real-time perceptions (observations) from pedestrians walking a course along the streets in a typical US metropolitan urban area.

Traditionally, the traffic flow is considered as the only parameter to access the LOS of traffic facilities. Tan et al. (2007) analyzed the pedestrian LOS with physical facilities and traffic flow operation along with user perception. Dandan et al. (2007) did not consider traffic flow as the only parameter to access the LOS of various traffic facilities. The authors 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. 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 an SP 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. 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, tress 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 LOS. Jensen (2007) developed methods for objectively quantifying pedestrian and bicyclist stated satisfaction with road sections between intersections. Pedestrian and bicyclist satisfaction models were developed using cumulative logit regression of ratings and variables. The results provided a measure of how well urban and rural roads accommodate Pedestrian and bicycle travel.

Zegeer et al. (2008) have developed default values to represent input parameters to the approach methodology used in the analysis of capacity and LOS of roads when they are difficult to measure or estimate. It has been observed that out of several default parameters, 19 parameters have shown a high degree of sensitivity in influencing service measure results in the appropriate methodology. Flannery et al. (2008) incorporated user perception to estimate LOS of Urban street facilities using a set of explanatory variables that describe the geometry and operational effectiveness. Clark (2008) 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. Shouhua et al. (2009) found that the LOS criteria of walkways proposed by HCM (2000) are not suitable for China. The authors have taken the 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. Ko et al. (2009) have conducted an extensive survey to know the performance measures that significantly affect truck driver's perceptions of LOS on various roadway types. Various performance measures through the analysis of survey data has been identified and the results lay the groundwork for future research that can focus on the actual development of quantitative LOS methods for truck mode. Cao et al. (2009) have conducted an SP 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 the 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. Ma et al. (2009) have identified crash risk factors associated with demographic characteristics, driving-related experiences, and aberrant driving behaviors among the occupational drivers of public transportation vehicles, and besides, established the influential paths among risk perception, risk-taking attitudes, and the risky driving behavior for improving LOS of public transportation. The data used for analyses were obtained from a self-reported questionnaire survey carried out among 248 taxi and bus drivers in Wuhan, China. Galicia et al. (2011) have used the TCQSM method to analyze SC-LOS for the fixed-route transit service. SC-LOS was determined from the percentage of transit-supportive area (TSA) that has the transit service coverage, which lies within a certain walking distance from a bus stop. This method failed to capture true trip demand, and hence underestimated TSA and SC-LOS along a corridor.

4. Conclusion

LOS analysis procedure of urban streets has been changing over time period. The concept of LOS was first introduced in the 1965 version of HCM. The LOS was measured in terms of travel time and ratio of traffic flow rate to capacity of road sections. The measuring parameters considered in the 1985 version of HCM were travel speed, traffic flow rate and capacity of road sections which were different to the 1965 version. Traffic flow rate have been increasing over a time period and with limited road space the travel condition is deteriorating. In this regard, Cameron (1996) and Maitra et al. (1999) have made an attempt to increase the number of LOS categories from the traditionally followed six to eight and nine, respectively. In HCM (2000), the ATS on road segments was considered as the MOE for the analysis of LOS of urban streets. The degree of accuracy of travel speed data collection has been significantly improved after the application of GPS and loop detector in the data collection. Hence, the quantitative method of analysis has become more accurate than before. All quantitative analysis methods followed up to year 2000 were based on some threshold values of MOEs. Kittelson and Roess (2001), Pecheux et al. (2000, 2004) and many more researchers have observed that LOS should not be based on quantitative analysis only. The authors have suggested that LOS analysis should be based on driver's perception on the QOS provided by urban street segments in several dimensions, including travel efficiency, sense of safety, and esthetics. It is observed that travel behavior under homogenous traffic flow condition is different from heterogeneous traffic flow condition. For heterogeneous traffic flow, Marwah and Singh (2000), Bhuyan and Rao (2010, 2011, 2012) have found that speed ranges of LOS categories are different from those mentioned in HCM (2000). LOS analysis methodology for heterogeneous traffic flow for developing countries is not established properly. A thorough investigation in this regard is very much required.

In recent years, researchers have been involved in the application of various soft computing methods such as fuzzy set theory, GA and ANN for LOS analysis of urban streets. Also, various statistical methods such as cluster analysis, uncertainty and reliability analysis, modeling and simulation of transportation system help for this purpose. Fuzzy set theory and fuzzy clustering help for the classification of urban streets into number of classes and LOS into various categories. GA is routinely used to solve useful classification problems through search and optimization. ANN is broadly used to know the classification pattern and their relation to the original data. Kikuchi and Chakroborty (2006) have successfully shown the application of uncertainty theory to the definition of LOS categories that have been traditionally followed. The LOS analysis procedure gradually becomes more accurate through the application of all these tools, including spatial analysis. To the known fact that researcher used motorized mode of transport for LOS analysis of urban streets. However, the research community felt the importance of a non-motorized mode such as the bicycle and walkways; hence included these in the HCM (2010). Now the procedure followed is for the multi-mode and considers both quantitative and qualitative variables for LOS analysis of urban streets. The results of the new user perception service measures will define LOS for pedestrians, bicyclists, and transit users, while traditional operational measures will be used to define LOS for auto users. User perception indices for auto users will be provided as additional performance measures when an applicable methodology exists. Hence, the HCM (2010) includes more pointed warnings to users to consider a range of performance measures, when they are available, instead of making decisions solely based on LOS. Beyond HCM (2010), LOS can go in one of three primary directions: (a) it can continue its present orientation, extending from facilities to systems; (b) it can be applied to points and segments or (c) it can be discontinued. LOS could be retained, but additional measures could be added and given equal weight in decision-making. It may be time to give up the comfort of a familiar language to force decision-makers to at least consider a broader set of numerical criteria. The change would not be easy or comfortable, but the benefits in more careful analysis and the ability to take into account a larger number of variables may be worth the effort. LOS analysis has got wide application in transportation planning, design, operation and allocations of limited resources among competing road segments of urban infrastructures. With the application of an intelligent transportation system, the LOS of urban streets can be analyzed more dynamically in future.

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