Determining urban street levels of service in developing cities: An effective solution for sustainability of automobile users

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Abstract. This study has developed an empirical model to assess Automobile Users' Level of Service (ALOS) under heterogeneous traffic flow conditions. Several geometric and traffic operational attributes are taken from 83 urban street segments. The proposed methodology incorporates an Ordinal logit analysis to model the ordered response of participants and to identify under what service category a segment is offering service for automobile use. The prediction performance of ALOS model was assessed in terms of pseudo R^2 values (0.744, 0.786 and 0.466 for Cox and Snell's, Nagelkerke and McFadden R^2 respectively). The findings from this research shows that, pavement condition index and on-street parking activities were observed to have the highest positive and highest negative influence on satisfaction level of drivers. Drivers are also dissatisfied due to interruptions caused by roadside commercial activities, oppositely moving traffic encounters *etc.* As a result of which, 72.55 % of street segments are offering ALOS categories of "C" or below. So, the highway authorities must take action by focusing on above issues for betterment of driver's riding quality.

Keywords: Level of service; Automobile mode; Ordered logit model; Perception survey; Mixed traffic flow.

1. Introduction

Land transport is the most important way of transportation because of coverage area. At the same time, managing the road network is turning out to be progressively challenging as demands increase and resources are limited. Emerging countries like India have highly heterogeneous traffic comprising of different vehicles of diverse operational features, which frequently leads to chaotic traffic growth and overcrowdings during traffic flow. To reduce these kind of problems, and to support appropriate traffic management Highway Capacity Manual (HCM) 2010, and several other handbooks like Transit Capacity and Quality of Service Manual (TCQSM) were suggested level-of-service (LOS) analysis procedures to evaluate road and traffic condition, to recognize the necessities and allocate funds for future implementation. These guidelines help in quantitative estimation of service quality using measure of effectiveness (MOE) like speed, number of stops and travel time to assess the performance of transportation infrastructure and to make investment decisions. However, the LOS criteria in the current version of those guidelines are grounded on the basis of perception survey in which Overall Satisfaction (OS) of road user's for provided road facilities are taken in to consideration. But the road users' opinion about individual transportation facilities (such as pavement condition, geometrical features, signs and marking, cleanliness and aesthetics etc.) were neglected. A set of LOS criteria based on user perceptions for separate aspects of transportation facility would be more credible than those based on overall satisfaction for any mode of transport. On the other hand, majority of the general population utilizes both private and public modes of transport as per their necessity. Designing and constructing infrastructure for the sustenance of one mode may adversely affect the operational enactment of alternative modes.

In order to evaluate the road users' expectation, this paper is structured in to several parts. The first part consists of investigating prominent factors of the transportation system that affects the satisfaction level of the road users on urban street segment. Then a customary questionnaire was developed with two main sections. In the first section demographic information of the participants were included, so that we can confirm the diversity in respondent's opinion according to their age group, gender, educational level, income level etc. The second section consists of thirty-three questions related to the investigated factors affecting road user's comfort level. The participants were requested to indicate the degree of satisfaction for different attributes and the Overall satisfaction for the respective segment on a seven-point scale starting from strongly disagree (1) to strongly agree (7). These surveys either seize traveller's mid-trip by orally interviewing them or by giving them a questionnaire to rate the attributes at a convenient time after finishing their trip.

2. Review of literature

This study focuses on user's perceptions of quality of service provided by urban streets under heterogeneous traffic flow condition. Ibrahim (2003) investigated car owners and non-car owner's perceptions towards different transport modes for shopping purposes. Attitudinal data is served as explanatory variables in mode choice models. They adopted both qualitative and quantitative researches. The results from the qualitative research found that shopper's perceptions on different transport modes for shopping purposes are affected by travelling attributes and socio-economic structure of the shoppers. In the quantitative research shoppers were asked to rate different transport modes for shopping purposes based on several variables. They found that each transport mode has its own unique set of attributes. Both Car owners and non-car owners shows different attitudes towards the public transport modes and the car. Lee et al. (2005) presented a new set of LOS standards for signalized crosswalks in Hong Kong commercial/shopping areas which takes into account the bi-directional pedestrian flow effects. For each LOS respondents were shown a set of five photographs under a specific flow ratio. The questionnaire data collected from the pedestrian interview survey were used to determine the various congestion boundaries under different bi-directional flows. The results show that pedestrian LOS is negatively influenced by the bi-directional flow. Araujo and Braga (2008) adapted a methodology for the qualitative LOS evaluation of pedestrian crossings at road junctions with traffic lights. Seventeen technical specialists were participated in the selection of the Performance Measures (Comfort, Safety, System Continuity), with their respective attributes. Respondents were asked to rate the pedestrian's satisfaction level in accordance with the attributes. Psychometric methods were used for evaluating the perceptions of the subjects based on Paired Comparison and Constant Sum. Khisty's methodology was adopted to relate the overall level of satisfaction with a qualitative LOS for the pedestrian facility. Rahaman et al. (2012) proposed a methodology for the assessment of walking environment and shopkeeper expectations in a medium-sized city center in Portugal. The perceptions of shopkeepers and pedestrians on walkways were analyzed using the Analytical Hierarchy Process (AHP) model. Data was collected by carrying out the Questionnaire, interview, and observation survey. The questionnaire included questions to compare five criteria (Identity, Connectivity, Hindrances, Illegal occupancy, Safety) and to express priorities from a pedestrian and shopkeeper point of view. Coefficient values from the model for each criterion were normalized to show the importance given by respondents. Results from the model indicated that both shopkeepers and pedestrians were enjoying the sidewalks according to their needs.

Petritsch et al. (2006) developed a field-calibrated pedestrian level-of-service (LOS) model that represents pedestrian's perceptions of how well urban arterials with sidewalks meet their needs. About 500 participants were presented a scoreboard in which they were asked to rate the facility that serves the needs as a pedestrian. Data was analyzed using the stepwise regression modelling in which traffic volume on the adjacent roadway and density of conflict points along the facility are taken as primary factors. Papadimitriou et al. (2010) identifies and analyses the perceived highway level of service in relation to personal attributes of road users like driver's age, gender, driving experience, familiarity with the road with respect to traffic conditions like vehicle capacity and volume to capacity ratio. They carried a field survey in which 264 subjects were taken a short interview and were asked to rate assess the traffic conditions in a scale from 1 to 10. The relationship between perceived level of service and traffic condition is analysed by means of a piecewise linear regression technique for different scenarios in terms of the number of perceived levels of service.

Joewono and Kubota (2007) aimed in improving the ridership quality in the existing paratransit system. They collected about 980 user perception data relating to quality of service, overall satisfaction and loyalty in using the paratransit system. Factor analysis is carried on the data and about eight factors with 35 attributes were extracted. The results of confirmatory factor analysis and the model reveals that in future paratransit is able to satisfy the need that was created by excess of private passenger trips over road transport. Musicant (2011) focused on measuring the company car drivers aberrant behaviours, safety attitudes and safety climate perceptions. For this they collected the attitudes of 110 company car drivers by preparing a 34-item questionnaire. Factor analysis is performed on the collected data and it yielded six factors. Three subgroups were identified in the K-means clustering technique procedure. The results show that the characteristics of the different subgroups of company car drivers can help in understanding the safety counter measures. Freeman et al. (2009) examined the driving behaviours in an Australian fleet with the help of the Manchester Driver Behaviour Questionnaire (DBQ). About 4792 professional drivers completed the survey by indicating their response on a six-point scale. Factor analysis is carried on the DBQ data and it revealed a three factor solution. They employed two logistic regressions for the traditional and the present DBQ factors. The results revealed that the number of kilometres driven by the participants gives a indication of predicting the crash involvement. Popuri et al. (2011) worked on the choice of public transportation to the workplace with the help of RTA (Regional Transportation Authority) Attitudinal Survey.

3. Study area and Data collection

To develop a preeminent model which suits for all traffic conditions, responses from different states were collected having different types of road conditions and different volumes of pedestrians, bicyclists, motorists and heavy vehicles. To increase the adequacy of the model in mixed traffic flow condition road users irrespective of age and gender have been collected from different cities of India like Rourkela of Odisha state, Visakhapatnam of Andhra Pradesh, and Thiruvananthapuram of Kerala state.

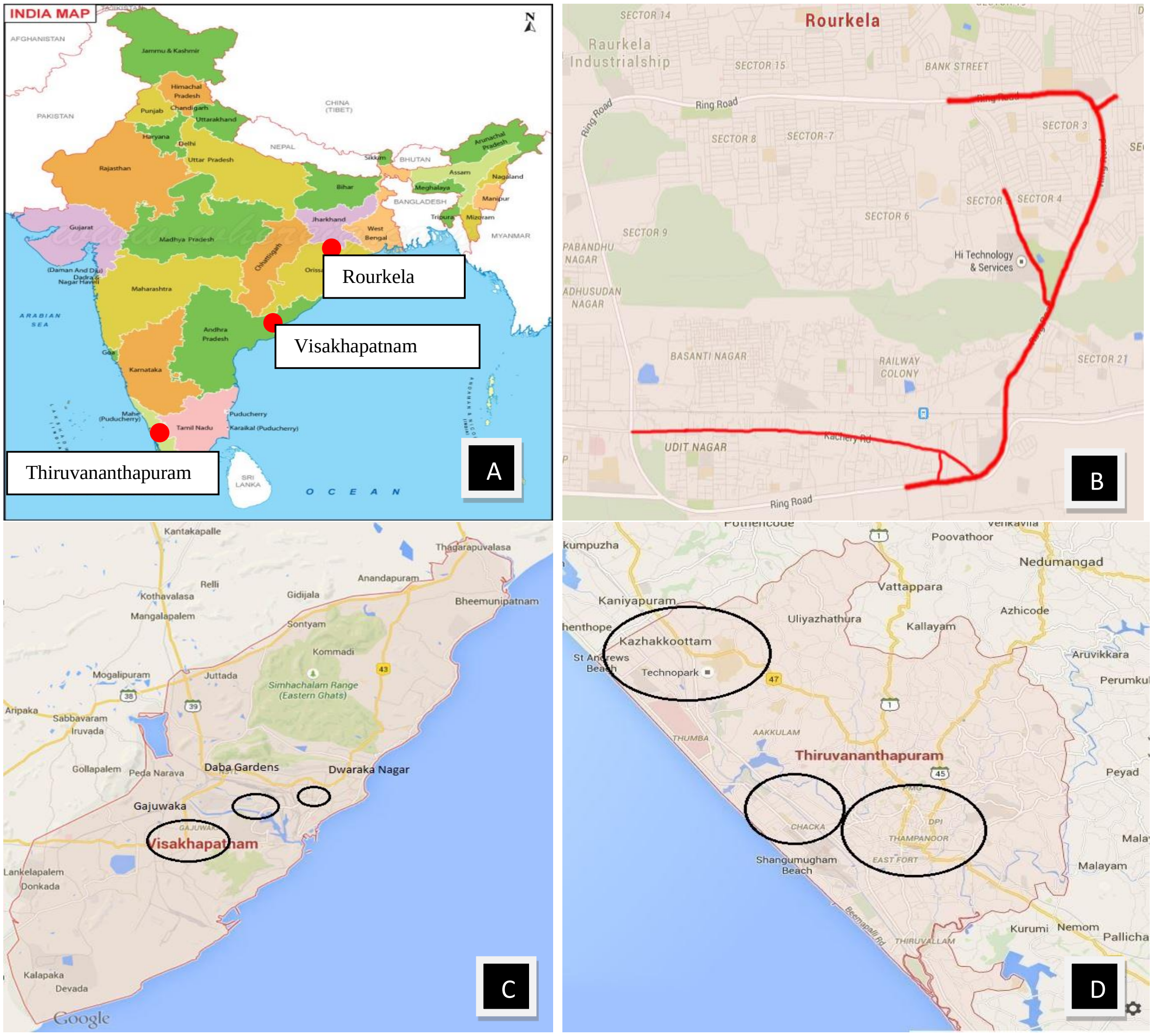

Figure 1 Map showing the data collection cities
B, C, D Study area and different site locations in Rourkela, Visakhapatnam and Thiruvananthapuram

There are various quality of service (QOS) factors affecting the road user's satisfaction levels on various transpiration facilities. A customary questionnaire was prepared containing 35 questions based on those QOS factors. The users' satisfaction level largely varies from person to person. So in this study perceptions of all the road users irrespective of gender, age group and mode of travel have been collected. User's perception data was collected using travellers' intercept surveys as the strengths of this survey is the representation of wider driving population, collection of relatively large sample size and cost effectiveness regarding the sample size. Survey was conducted at residential as well as commercial areas in all the three cities.

4. Study methodology

The 33 statements in the questionnaire capture information on various aspects of transportation system. But there are two reasons for not using all the statements as input variables in a choice model. First reason is that there is a high degree of correlation between these statements and second is that using 33 variables is not desirable from the standpoint of model parsimony. The captured information of the 33 statements is condensed into manageable and uncorrelated set of variables by adopting factor analysis methodology.

4.1 Factor Analysis

The purpose of the factor analysis is to reduce a large set of data to smaller subsets of measurement variables. Factor analysis has the following uses: (i) understanding the structure of a set of variables; (ii) construction of a questionnaire to measure an underlying variable; (iii) reduction of a data set to a more manageable size while retaining as much of the original information as possible.

The assumption made by the factor analysis is that the ratings on 33 statements are produced by some underlying and unobserved attitudes. The basic form of the factor analysis model is explained by equation (1) as follows:

$$X_{ji} = \sum_{k=1}^{m} (\lambda_{jk} F_{ki}) + \varepsilon_{ji}, \quad \forall j = 1,2,.....,J \text{ and } \forall i = 1,2,.....,N \qquad (1)$$

Where, X_{ji} is the rating on statement j for person i; F_{ki} is the value of the k^{th} factor for the person i; λ_{jk} is the relation of the j^{th} variable with the k^{th} common factor, also known as the loading; and ε_{ji} represents the error term.

The equation (1) assumes that there are J statements, N observations and m factors in the sample. It should be noted that the factor scores (F_{ki}) are not observed. In order to maximize the information maintained from the original statements, factor analysis computes both the factor scores and the loadings.

KMO & Bartlett's Test of Sphericity is the main aspect in Factor Analysis. The KMO statistic is a Measure of Sampling Adequacy, both overall and for each variable (Cerny and Kaiser 1977). KMO values greater than 0.8 can be considered good, i.e. an indication that component or factor analysis will be useful for these variables. The Bartlett's Test of Sphericity relates to the significance of the study to show the validity and suitability of the responses collected to adress the problem. The Bartlett's Test of Sphericity less than 0.05 is recommended as a suitable value in factor analysis.

Another important aspect mentioned in this study is the Rotated Component Matrix. While deciding how many factors one would analyze is whether a variable might relate to more than one factor. Rotation maximizes high item loadings and minimizes low item loadings, thereby producing a more interpretable and simplified solution. In this study orthogonal varimax rotation technique is used, that produces factor structures that are uncorrelated. Reliability analysis is represented by cronbach's alpha, which is used to measure the consistency of a questionnaire or an individual component.

4.2 Multiple linear Regression Technique

From the factor analysis eight factors have been extracted. The statement scores under each factor is summed up and a mean value is taken for each person. The mean values of eight factors are taken as independent variables. OS scores of each individual is taken as dependent variable. A model was developed by multiple regression technique, which is a way of predicting an outcome variable from several predictor variables. This technique attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to the observed data. Each predictor variable has its own coefficient and the outcome variable is predicted from a combination of all the variables multiplied by their respective coefficients plus residual term as shown in the equation (2).

$$Y_i = b_0 + b_1 X_1 + b_2 X_2 + ... + b_n X_n + \varepsilon_i \quad \text{for i} = 1,2,...\text{n} \tag{2}$$

Where, Y_i is the outcome variable, b_1 is the coefficient of the first predictor (X_1), b_2 is the coefficient of the second predictor (X_2), b_n is the coefficient of the n^{th} predictor (X_n) and ε_i is the difference between the predicted and the observed value of *Y* for the i^{th} participant.

The eight independent variables extracted from factor analysis are: cross-section of roadway design (RD), arterial operations (AO), intersection operations (IO), signs and markings (SM), maintenance (M), aesthetics (A), road user behaviour (RB) and other facilities (OF). The dependent variable is the OS.

80% of the data is used for analysis in regression and remaining 20% of the data is used for validation.

4.3 K-means Clustering

The output of the proposed model i.e. OS scores are classified in to six LOS categories (A-F) using k-means clustering technique. *K*-means clustering is one of the simplest algorithms to solve the classification problem. A *k*-means cluster analysis on a data set initially clusters the data based on *K* points representing group clusters. Each object gets assigned to group with closest centroid and then the same procedure is repeated by calculating K centroids until there is no change in centroids. From a data set of *N* points, *k*-means algorithm allocates each data point to one of *c* clusters to minimize the within-cluster sum of squares, where the number of clusters is $1 < c < N$. Mathematically,

$$D_{ik}^2 = (x_k - v_i)^T (x_k - v_i), \quad 1 \le i \le c, \quad 1 \le k \le N. \tag{3}$$

Where, $D^2{}_{ik}$ is the distance matrix between data points and the cluster centers, x_k is the k[th] data point in cluster i, and v_i is the mean for the data points over cluster i, called the cluster centers.

$$v_i^{(l)} = \frac{\sum_{j=1}^{N_i} x_i}{N_i} \tag{4}$$

$$\max\left|v^{(l)} - v^{(l-1)}\right| \neq 0 \qquad (5)$$

Where N_i is the number of objects in the cluster *i, j* is the j[th] cluster; *l* is the number of iterations. It is to be noted that for the above equation (4) $1 \le i \neq j \le c$.

5. Result and Analysis

The collected data sets with respect to thirty-three questions pertaining to various QOS factors of transportation system were analysed using SPSS (Statistical Package for the Social Sciences) software.

5.1 Factor Analysis

A principal component analysis was conducted on the 33 statements with orthogonal rotation (varimax). Table 2 represents the results of KMO and Bartlett's test. In the present study, KMO statistic value is 0.836 (i.e. >0.8) which falls into the range of good, so that the sample size is useful and adequate for factor analysis. All the KMO values for individual statements were greater than 0.5 which is an acceptable limit. For the sets of data Bartlett's test is highly significant (p<.001) and therefore factor analysis is appropriate. A significant test value which is <0.05 in Bartlett's test shows that the R-matrix is not an identity matrix. This represents that there are some relationships among the variables included in the analysis.

Table 2 KMO and Bartlett's test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.836
Bartlett's Test of Sphericity	Approx. Chi-Square	4686.756
	df	528
	Sig.	.000

The Scree Plot, which is shown in Figure 2 displays the percentage of total variance explained by each factor. Beyond 8 factors the incremental variance explained was very low. Hence for easy interpretation the factors were "rotated" using the varimax technique in such a way that each variable will be loaded heavily onto a single factor. This technique helps in the clear identification of variables those are measured under each factor and also minimizes the overlap across factors.

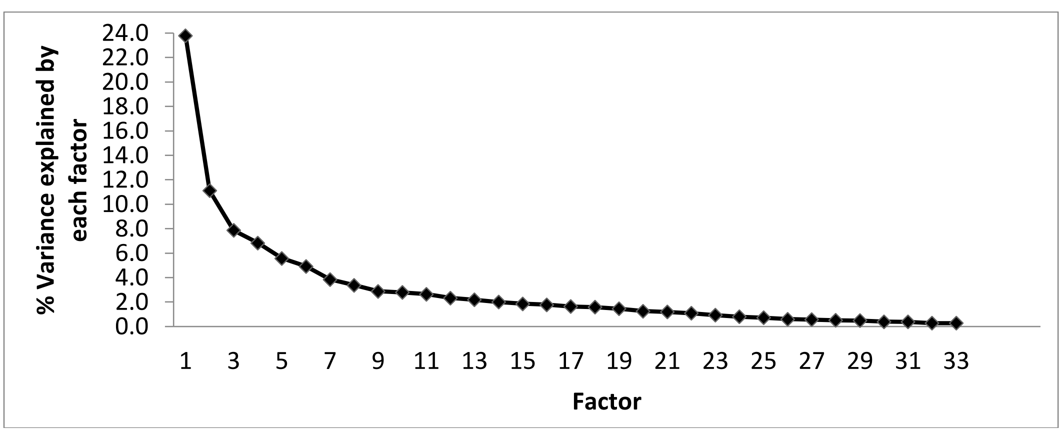

Figure 2 Scree plot from principal component analysis

5.2 Multiple linear Regression analysis

From the factor analysis eight factors has been extracted and the table 4 representing the eight factors are considered as independent variables and the OS is considered as dependent variable. The model summary table shows the R, R^2 values. R value represents the multiple correlation coefficient between the predictors and the outcome. R^2 value is a measure of how much of the variability in the outcome is accounted for by the predictors. In this model its value is 0.709, which means that all the eight independent variables accounts for 70.9% of the variation in overall satisfaction. The adjusted R^2 value represents how well our model generalizes. Tble 5 shows the Durbin- Watson value is 2.163 which is close to 2 showing that it is better and the assumption that the residual terms are not correlated is met.

Table 5 Summary of the multiple regression model

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
.842	.709	.683	.377	2.163

Table 6 shows ANOVA results in which it tests whether the model is significantly better at predicting the outcome than using the mean as a best guess. F ratio represents the ratio of how good the model is compared to how bad it is. The value of greater than 1 represents the improvement due fitting the regression model is much greater than the inaccuracy within the model. For this model F-value is 27.69 and the significance value is 0.00. The results tells us that the model is significantly improved our ability to predict the outcome variable.

Table 6 ANOVA test Results

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	31.549	8	3.944	27.690	.000
Residual	12.961	91	.142		
Total	44.510	99			

Table 7 represents the model parameters consisting of b values, t- statistic, and the significance of each coefficient. B-values indicate the individual contribution of each predictor to the model. If we replace the b-values in equation (3.2) then the model is as follows.

$$OS = -0.932 + 0.288\ RD + 0.049\ AO + 0.258\ IO + 0.044\ SM + 0.114\ M + 0.092\ A + 0.029\ RB + 0.084\ OF \qquad (3)$$

Where, OS = overall satisfaction

RD = Cross-Section of roadway design

AO = arterial operations

IO = intersection operations

SM = signs and markings

M = maintenance

A = aesthetics

RB = Road user behaviour

OF = other facilities

The b-values gives the relationship between overall satisfaction and each predictor. In this model all the predictor values are positive indicating that there is a positive relationship between overall satisfaction and each predictor. Each of these beta values has an associated standard error indicating to what extent these values would vary across different samples and these are used to determine whether or not the b-values differs significantly from zero. A t- statistics can be derived that tests whether a b-value is significantly different from 0. The t-test associated with a b-value is significant (sig. <0.05) then the predictor is making a significant contribution to the model. For this model all are significant independent variables of overall satisfaction. The larger the value of t, the greater the contribution of that predictor.

Table 7 Model parameters

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	-.932	.362		-2.573	.012
RD	.288	.057	.402	5.067	.000
AO	.049	.053	.080	.935	.035
IO	.258	.054	.320	4.818	.000
SM	.044	.050	.053	.888	.037
M	.114	.052	.137	2.181	.032
A	.092	.049	.113	1.863	.046
RB	.029	.046	.040	.633	.042
OF	.084	.045	.130	1.874	.044

5.3 Cluster Analysis

The LOS scores obtained from the model are clustered into six groups by means of k-means clustering. Silhouette value obtained is 0.7 and so *k*-means clustering gives the best ranges. The ranges of LOS scores for the six groups are as follows.

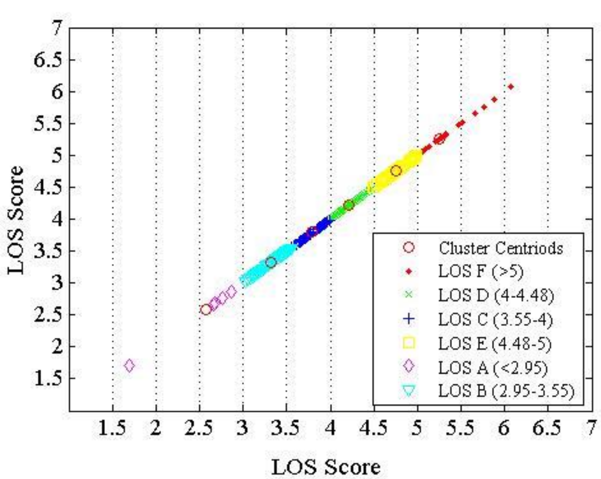

Figure 3 Clustering of LOS scores

5.4 Validation of Regression Model

20% of the data is used for validation purpose as shown in figure 4. A graph is plotted between predicted OS scores and observed OS scores. The slope of the trend line is found to be 43 degrees which is close to 45 degrees indicating that the validation of the model is good.

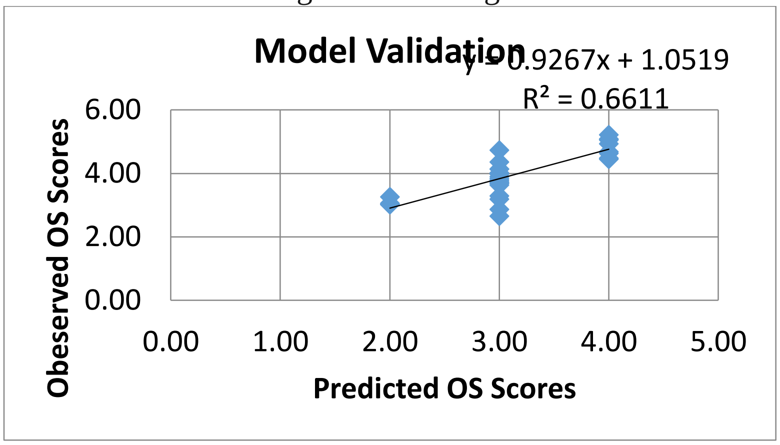

Figure 4 Scatter plot of observed vs. predicted OS scores

6. Conclusion

The proposed framework includes statistical model that can identify significant factors affecting the satisfaction. The apprehended data of 33 questions is summarized into convenient and uncorrelated set of variables using factor analysis. To determine the suitability of the correlational matrix for factor analysis, the computation involves the Kaiser-Meyer-Olkin measure of sampling adequacy (KMO). All the KMO values for individual statements greater than 0.5 are considered as acceptable. In the present study, KMO statistic value is 0.836, so that the sample size is adequate for factor analysis. Five factors i.e. cross-section of roadway design (RD), intersection operations (IO), arterial operations (AO), maintenance (M), signs and markings (SM) have high reliability (Cronbach's alpha > 0.8) and last three factors i.e. aesthetics (A), road user behavior (RB) and other facilities (OF) have relatively low reliability (Cronbach's alpha is < 0.8). Then the model was developed using multiple regression analysis method considering all the eight factors as independent variables and OS as dependent variable. The model shows R^2 value is 0.709, which means that all the eight explanatory variables explains 70.9% of the variation in overall satisfaction. Durbin- Watson test result was found out to be 2.163 which is close to 2, shows that the residual terms are not correlated. The model outputs are clustered into six groups with the help of k-means clustering with Silhouette value of 0.7. From the total data 80% was used for model development and remaining 20% was used for validation purpose. While validating the proposed model the slope of the trend line was found out to be 43 degree by plotting a graph between predicted OS scores and observed OS scores.

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