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Fuzzy Logic Based User Perceived Level of Service of Signalized Intersection under Heterogeneous Traffic Condition

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Abstract

The users' perception of Level of Service (LOS) are influenced by many quantitative and qualitative attributes. In India, the people are from different economic backgrounds and have different living standards. Moreover, the presence of a wide variety of vehicle classes and the absence of any lane discipline all together make the scenario complex. Delay may not be the only factor that influences their perception. Users make judgments about the service quality based on their perceptions about various factors in linguistic terms like 'good',' average' or 'poor'. The subjective nature of the users' perception of the LOS of signalized intersection can be captured using a fuzzy logic system. The present study aims at modeling the user perceived LOS (UPLOS) at signalized intersection using fuzzy logic approach. The user perception survey carried out at fifteen signalized intersections from various cities of India forms the database for the present study. Through an importance-satisfaction analysis, it was found that waiting time, road surface quality and presence of pedestrians are the three most important factors that influence the users' perception of LOS at signalized intersection under heterogeneous traffic condition. To model the perceived LOS based on these factors, the Fuzzy Inference System has been used. Triangular membership functions and centroid method of defuzzification has been used. The analysis results show that the proposed fuzzy logic user perceived LOS model can be used as a non-traditional method for arriving at the perceived LOS of signalized intersection under heterogeneous traffic.

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Keywords: Fuzzy logic; Level of service; User perception; Heterogeneous traffic; Signalized intersection

Introduction

Signalized intersections are the critical points in a transportation network. The Level of Service (LOS) indicates the operational efficiency of any road facility. The Highway Capacity Manual (HCM 2010) defines LOS as "a qualitative measure describing operational conditions within a traffic stream and their perception by motorists and/or passengers". The definition of LOS has gone through many modifications and deletions over the past years. As users' are the integral component of any transportation system, it is important to consider the users' perception. The first direct inclusion of the road users' perception in the LOS definition was made in HCM 1985. There are six levels of service ranging from LOS A to LOS F. These letter grades are used to translate the results of traffic operational analysis so that they are readily understandable. While the LOS measure has had many critics over the years, it continues as a universal adoption among the traffic engineers, mostly because of its ability to explain the operational efficiency of a facility to the non-technical decision makers. However, the concept of users' perception has not been taken care of in defining the LOS categories.

Many researchers suggested that using delay alone as the service measure lacks behavioral investigation and justification. Considering delay as the sole quality of service measure leads to the ignorance of other qualitative aspects

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which influence the LOS (Chakroborty and Kikuchi 1990; Zhang 2004). Kittelson and Roess (2001) recommended that the use of a single criterion for determining the LOS should be abandoned, and multiple service measures should be included. In supplementary to delay, several other influencing attributes of signalized intersections need to be considered for the better representation of the level of service.

In India, the people are from different economic backgrounds and have different living standards. Moreover, the presence of a wide variety of vehicle classes and the absence of any lane discipline all together make the scenario complex. Waiting time may not be the only factor that influences their perception. A study by Sekhar et al. (2016) stated that the increase in traffic volume and the underdeveloped road network along with the poor maintenance system in India resulted in deteriorations to the existing pavement leading to poor pavement surface quality. The presence of potholes, cracks, and rutting not only causes congestion and accidents but also leads to the reduction in the speed of the vehicles and causes severe discomfort to the users. In such cases, users may give higher priority to road surface quality than the waiting time. Similar is the case with poor pedestrian facilities. The poorly maintained foot-over bridges and the longer cycle time at the signalized intersections lead to pedestrian noncompliance with the traffic signal. This would significantly cause discomfort to the motorized vehicle users. Therefore, the use of control delay as the sole service measure cannot be justified for Indian traffic scenario. Due to the involvement of multiple factors in the users' perception, modeling the user perceived LOS is a complex task. Hence, for traffic engineers, transportation planners, and the decision makers it is a real hectic task to identify the influencing factors and incorporate those into the LOS analysis.

Fuzzy logic is shown to be a very promising mathematical approach for modeling traffic and transportation processes characterized by subjectivity, ambiguity, and uncertainty and imprecision. Human decision making is subjective in nature and is often related to linguistic terms. Users make judgments about the service quality based on their perceptions in linguistic terms like 'good',' average' or 'poor'. Due to the fact that human decision making is more consistent with fuzzy logic in comparison with crisp mathematics, it seems that fuzzy logic could be a logical tool to map such areas. Hence, the present study aims at modeling the user perceived LOS (UPLOS) at signalized intersection using fuzzy logic approach.

Literature Review

The very first Highway Capacity Manual, HCM (1950) did not mention the word 'Level of Service' nor explained any concept similar to that. But according to many researchers, 'practical capacity' explained in the manual can be treated as a predecessor to the LOS (Roess 1984). The concept of LOS was firstly introduced in HCM 1965. For determining the LOS at signalized intersections, HCM 1965 used load factor. HCM 1985 adopted the average stopped delay as the service measure and defined LOS as "a qualitative measure describing operational conditions within a traffic stream and their perception by motorists and passengers". This is the first direct inclusion of road users' perception in the LOS definition. The LOS criterion was changed from stopped delay to control delay in HCM 1997 revision.

There is relatively little research regarding the customer satisfaction or user perception of the LOS at signalized intersection. The pioneering study on user perception of signalized intersection LOS was carried out by Sutaria and Haynes (1977). A road-user opinion survey was conducted for the data collection. The survey involved depicting and rating different traffic situations at a signalized intersection. Over 300 drivers rated the randomly arranged films in terms of appropriate LOS. The results from the group attitude survey indicated that delay was considered the most important factor both before and after viewing the film segments.

Pecheux et al. (2000) carried out a controlled laboratory study at the Pennsylvania Transportation Institute (PTI). Video data from 24 approaches were collected and 100 subjects were involved. The stopped delay was measured from the field. To acquire particulars regarding the various factors influencing the user perception of LOS, a questionnaire survey was carried out. After watching the video, subjects were requested to note down the waiting time and were requested to rate the quality of service. They found that drivers can perceive only up to 3 or 4 levels of service contrary to what HCM specifies. Authors found that the subjects were more tolerant to delay than what the HCM suggests; also, many of the subjects used more than one criterion while rating LOS.

To overcome the limitation of the step-function quality descriptor, Fang et al. (2003) came up with the concept of continuous LOS. Using fuzzy clustering technique authors defined LOS ranges based on user perception of delay at signalized intersection. Each approach has two LOS-one with the degree of belongingness greater than 0.5 (major LOS) and the other with less than 0.5 (minor LOS). Fang and Pecheux (2009) reveals that the users can perceive six levels of service, but not as the one defined by HCM. They proposed new LOS by clubbing LOS A and B and dividing LOS F. The limitation of both these studies are they considered only the delay for establishing the LOS.

Kita (2000) proposed a universal LOS measure for road traffic, based on users' perception of the driving environment. Aggregated driving utility estimated by the driver's utility function with surrounding driving environment was taken as the LOS measure. The study was conducted at the merging section of freeway. Using the utility maximization principle, Kita and Kouchi (2011) developed models to estimate the perceived LOS. This perceived LOS was for point basis, which then aggregated gives, the section-based LOS.

Goyal (2005) conducted a simulator-based pilot study in Florida to compute qualitative measures of drivers at different intersection scenarios. Their main objective was to illustrate the feasibility of driving simulator. Forty subjects in three age groups were recruited for the study. They found that the drivers get frustrated when they are trapped behind a left turning vehicle in a combined left and through lane intersection.

Wochinger and Martin (2005) tested the relationship between LOS proposed by HCM 2000 and the perceived rating of LOS of urban streets. They found that the HCM method predicted approximately 35% of the variance in the mean driver ratings. This suggests that there are factors other than the service measure in the HCM that affects the drivers' quality assessments. Flannery et al. (2006) emphasize the need for a better analytical method to reflect the public's perception of the service provided by various highway facilities.

For assessing user perception of a transportation facility, a generalized fuzzy approach was put forward by Lee (2006). Two fuzzy approaches used for the study are the fuzzy aggregation (weighted average) method and hierarchical fuzzy inference system. They also conducted a comparison linking the perception of transportation experts and the public to find whether the opinion by common users can be a surrogate opinion of experts. They found that the decision-making trend of experts and common users are not statistically different while responding to a 5-point scale survey. The opinion of 64 common users and 74 experts were used for the study. Chen et al. (2009a; b) initiated the application of fuzzy neural networks–based approach to determine the LOS for signalized intersection based on user perceptions. A methodology based on visualization was applied to collect user perceptions of LOS. VISSIM was used to simulate the subject intersection and record the animation videos.

To incorporate the concept of user perception into the LOS, Zhang (2004) used two alternative methodologies like fuzzy weighted average method and fuzzy logic method. The author stated that the fuzzy numbers that replace the rigid LOS values reflect the drivers' perceptions. 1300 responses obtained from a web-based survey forms the data for the study. An ordered probit model was developed by Zhang et al. (2007) for finding out the user perception of protected left turn signals. Responses from 2,017 subjects were used for the modeling. They found that as the size of intersection increases, users felt difficulty in making turns without protected left-turn signal. Later in 2011, Zhang and Prevedouros came up with the concept of composite LOS measure. Pavement markings, left turn treatment, and delay were taken as the input factors. They found that fuzzy logic is the best method to model user perceptions.

A study on drivers' perception of LOSs at signalized intersections was carried out by Jou et al. (2013) especially for motorcycle riders and car drivers in Taiwan. Pre-recorded videos of different LOSs were presented to the respondent in the survey. After watching the video, a questionnaire was provided to the respondents. Data obtained from 527 samples (264 from car drivers and 263 motorcycle riders) were used for the study. The study considered seven categories of factors like traffic flow, pavement condition, and highway geometric design, and traffic control, distribution of vehicle types, hardware facility, and weather, with 20 subcategories. Both car drivers and motorcycle drivers gave higher emphasis on uneven pavement flatness. An ordered probit model was used to estimate the effects of important factors on the driver's perception of different LOSs at a signalized intersection. The results show that individual trip, socioeconomic, road-related characteristics (e.g., pavement condition, geometric design, traffic control), and weather conditions are all significant variables influencing the driver's perception towards different LOS at a signalized intersection.

The concept of user perception was incorporated into the LOS analysis at toll plaza by Obelheiro et al. (2011). For obtaining the user perception, various scenarios were developed in VISSIM simulation software. They found that queue length at the toll booth is the most influencing factor affecting the user perception. Correia and Wirasinghe (2007) and Correia et al. (Correia et al. 2008; 2008) developed the user perceived LOS standards for airport facility. They used the psychometrical scaling theory to convert the user perceived qualitative data into quantitative data. The factors considered are waiting time, processing time and area available. They used the linear regression analysis for the LOS modeling.

Previous studies on the level of service provide a poignant evidence that determining LOS based on a single criterion leads to the ignorance of other qualitative factors. Hence, it provides insight to the fact that quantification of LOS involves a complex integration of many traffic and user related parameters, which can be quantitative and/or qualitative. Through this study, an endeavor was made to incorporate the subjective nature of the users' perception of the LOS of signalized intersection using a fuzzy logic approach.

Methodology

The theory of fuzzy logic was introduced by Zadeh (Zadeh 1965), wherein the degree of belongingness of an element to a set is described in terms of the membership function. A fuzzy logic system mainly consists of three operations, namely-fuzzification, fuzzy inference, and defuzzification. Fuzzification is the process of converting a crisp input value to a fuzzy number. This is done by assigning membership values to the data. Classical set theory, considers only two membership (1 or 0), i.e. either an element belongs to that particular set or not. But in the case of fuzzy logic, each data point will have some degree of belongingness and that is indicated by the membership function. There are different types of membership functions like triangular, trapezoidal, sigmoidal etc. From the available ambiguous information using deductive process, human beings makes decision. Fuzzy Inference System (FIS) is a deductive reasoning method with linguistic terms using fuzzy logic. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. There are two types of fuzzy inference systems and they are Mamdani-type and Sugeno-type. These two types of inference systems vary in the way outputs are determined. Mamdani-type inference expects the output membership functions to be fuzzy sets. In Sugeno-type systems, output membership functions are either linear or constant. Mamdani-type fuzzy inference system is used for the present study. It consists of IF-THEN rules. IF-THEN rules will be of the form:

IF <antecedent>, THEN <consequent>

A typical fuzzy rule would be

IF <Waiting time is very high > and <Road surface quality is poor >and <Presence of pedestrians are high>, THEN <the LOS is F>

Defuzzification is the process of converting the fuzzy output to crisp output. Fuzzy output cannot be used as such for practical applications, hence that needs to be converted to crisp quantities. Some of the methods of defuzzification are centroid method, maximum height, means of maxima, and modified height method. Centroid method is the most commonly used one. The centroid method analyses the combined shape of membership function which gives us comparatively good results as compared to other methods. In this method, if there are number of parameters given and each parameter have its own specified membership function then, the final shape of the membership function is analyzed as per specified fuzzy rule to give the result of membership value on the basis of the centre of gravity of shape of membership functions developed from different membership function parameters.

Data Collection

In order to model the perceived LOS at signalized intersection, it is necessary to have information on how users perceive the overall LOS of an intersection, what are the influencing factors, and how much the users are satisfied with these factors. User perception survey has been carried out to obtain the required data. The data collected as a part of the multi-institutional project "Development of Indian Highway Capacity Manual", sponsored by Government of India has been used for this study. The data obtained from the user perception survey was checked for errors or incomplete responses. A total of 8458 samples were obtained from the user perception questionnaire survey. The study locations include New Delhi, Kolkata, Mumbai, Surat, Baroda, and Ahmedabad. All the selected intersections are fixed time signals with either three-legged of four-legged. Some intersections included in the study are having very good flow characteristics with wide approaches, flared geometry at the stop-line, and exclusive left-turn lanes. Whereas, traffic flow at some of the intersections are influenced by the pavement conditions, roadside activities and parking. Hence, this data represents the wide variation of traffic characteristics at the intersections prevailing in the Indian context. Table 1 gives the location details of the study intersections.

A questionnaire was designed to obtain data regarding the users' socio-economic information, travel information and perception related information. In the perception related information, users are asked about their perceived waiting time at the signalized intersection. A retrospective approach (the users' time estimation based on the memory related process) with category rating technique is used to obtain the perceived waiting time from the users. In category rating, the surveyor presents the temporal interval and the respondents locate the perceived waiting time in one of the 'm' ordered categories. The delay threshold in the United States HCM ranges from less than 10 seconds for LOS A to more than 80 seconds for LOS F. But these thresholds are not based on users' perception but based on the perception of transportation experts (Pecheux et al. 2000). Also, from the field, it was understood that the HCM 2010 do not adequately address the entire spectrum of the real world delay ranges in developing countries like India. Waiting for more than one and a half minutes is not an uncommon situation in India. Hence, an uneven time interval ranging from less than 30 seconds to more than 4 minutes has been used in this study.

Table 1. Location details of the study intersections.

Intersection Identity	Name of Intersection	City	Coordinate
A	Aashirwad Chowk	New Delhi	28° 35' 47.9" N 77° 2' 59.9" E
B	Deepali Chowk	New Delhi	28° 41' 53.1" N 77° 7' 11.6" E
C	Depot Chowk	New Delhi	28° 35' 41.3" N 77° 4' 18.7" E
D	Firozshah-KG Marg Junction	New Delhi	28° 37' 22.1" N 77° 13' 31.5" E
E	NTPC Chowk	New Delhi	28° 36' 3.6" N 77° 22' 20.9" E
F	PTS Chowk	New Delhi	28° 31' 58.1" N 77° 11' 45.0" E
G	Stadium Chowk	New Delhi	28° 35' 23.6" N 77° 20' 9.5" E
H	Vardhaman Chowk	New Delhi	28° 35' 29.2" N 77° 3' 27.6" E
I	Vijay Char Rastha	Ahmedabad	23°02'34.1"N 72°32'56.01"E
J	GEV Circle	Vadodara	22°18'37.7"N 73°9'54.3"E
K	Rangila Park Intersection	Surat	21°10'29.9"N 72°48'18.9"E
L	IIT Bombay Main Gate Intersection	Mumbai	19° 7' 30.3" N 72° 54' 59.7" E
M	Shivaji Chowk	Mumbai	19° 4' 28.3" N 72° 59' 52.0" E
N	Kona Intersection	Kolkata	22°34'31.6"N 88°18'06.5"E
O	Rashbehari Intersection	Kolkata	22°31'02.4"N 88°21'08.6"E

The factors influencing the user perceived LOS at signalizes intersection are identified from the literature and incorporated in the questionnaire. The factors considered include waiting time, road surface quality, visibility of traffic signals from queue, signs and road marking, presence of heavy vehicles, presence of pedestrians, obstructions due to parked vehicles, bus stops etc. and scenery/aesthetics. Users were requested to rate the factors according to their importance in influencing the quality rating of a signalized intersection in a 1-5 scale. '1' indicates the factor is very unimportant and '5' indicates very important in influencing their perceived LOS. In addition, qualitative (poor, moderate or good) data were collected from the respondents regarding the level of satisfaction with each factor for the subject intersection. Finally, the users were requested to give the overall rating of the intersection in 'A-F scale'. A indicates "very good" and F indicates "very poor" operating condition.

Importance-Satisfaction Analysis

An importance-satisfaction (IS) analysis was carried out to identify the most important and satisfying factor. This would also help to identify those factors that need the most improvement. The IS rating is computed using the formula given by Iseki and Smart (2012). IS rating is the product of importance rating and the dissatisfaction rating. Importance rating of a factor is the percentage of users who rated the factor as very important, and satisfaction rating of a factor is the percentage of users who indicated a high level of satisfaction with that factor.

Table 2 gives the ranking of the factors based on importance, satisfaction and IS rating. Low IS rank calls for greater attention to that factor indicating that there is a greater need for improving that factor. In the present study, waiting time has the lowest IS rank followed by the road surface quality. This indicates that the waiting time is the most important factor to the users while perceiving the level of service of a signalized intersection and it is the least satisfied factor as the users are concerned. Road surface quality and presence of pedestrians are the second and the third most important factors. To reduce the intricacy of using multiple input variables, only the three most important determinants of user perceived LOS are used for fuzzy modeling.

Table 2. Importance-Satisfaction (IS) analysis.

Factor	Importance Rating (%)	Satisfaction Rating (%)	IS	
			Rating (%)	Rank
Perceived waiting time	79.95	6.57	74.70	1
Road surface quality	43.14	15.15	36.61	2
Visibility of traffic signals from queue	36.40	18.7	29.60	4
Signs and road marking	33.05	29.92	23.16	6
Presence of heavy vehicles	31.78	22.37	24.67	5
Presence of pedestrians	40.53	19.45	32.65	3
Obstructions due to parked vehicles, bus stops etc.	25.96	31.25	17.85	7
Scenery/aesthetics	23.11	32.66	15.57	8

Development of Fuzzy Logic Based User Perceived LOS Model

To develop the fuzzy logic based user perceived LOS model, Fuzzy Logic Tool Box in MATLAB software has been used. As from the IS analysis it was found that waiting time (WT), road surface quality (RSQ) and presence of pedestrians (PED) are the determinants of user perceived LOS (UPLOS) at signalized intersection under heterogeneous traffic condition, these factors have been considered as the input to the fuzzy logic based LOS model. The output of the model is the user perceived LOS.

Development of Membership Functions

Of the three input variables, waiting time is divided into six membership functions namely ‘very less’, ‘less’, ‘moderate’, ‘high’, ‘very high’. The other input variables, road surface quality and presence of pedestrians are divided into three membership functions. This is because in the questionnaire six ordered choices were given for the users’ perceived waiting time and in the satisfaction rating the other two variables were given three options. For road surface quality the membership functions defined are ‘poor’, ‘moderate’, and ‘good’. For presence of pedestrians, the membership functions defined are ‘low’, ‘medium’, and ‘high’. The output of the fuzzy model is the user perceived LOS ranging from LOS A to LOS F. Triangular membership functions are assigned to both the input and output variables.

Figure 1 shows the membership function for the input variables and the output variable. The range of the input variable ‘waiting time’ varies from 0 to 6. 0 to 1 indicates the perceived waiting time is less than 30 seconds, 1-2 indicates the perceived waiting time is between 30 seconds to 1 minute, 2-3 indicates the perceived waiting time is between 1 to 2 minutes and so on. The range of the other two input variables is from 0 to 2, which is divided into three equally overlapped membership functions. The output variable range varies from 0 to 6 which is divided into six equally spaced triangular membership functions indicating LOSA to LOS F.

Development of Fuzzy Inference System

The fuzzy rule-based system is created based on the relationship between input and output variables. As the number of membership functions for each input variable increases the number of possible IF-THEN rules also will increase. 70% of the collected data has been used as the training data set for generating the IF-THEN rules. Remaining 30% data has been used for testing the model. As there were 5*3*3 membership functions for the input variables a total of 45 IF-THEN rules were framed. For example, a typical rule will be of the form:

IF <Waiting time is very less > and <Road surface quality is good >and <Presence of pedestrians are low>, THEN <the LOS is A>

In this FIS System minimum implication method, maximum aggregation method and centroid defuzzification method were used for modeling. The rule viewer option in MATLAB is used to view the fuzzy inference diagram. This rule viewer can be used as a diagnostic to see, which rules are active, or how individual membership function shapes influence the results. Figure 2 shows the rule viewer window. The first three columns of the figure show the membership functions referenced by the antecedent or the if-part of each rule. The fourth column of plots shows the membership functions referenced by the consequent or the then-part of each rule. For the input {WT = moderate, RSQ = moderate, PED = medium}, the crisp output obtained in 2.4. This indicates for the given input the perceived LOS is LOS C.

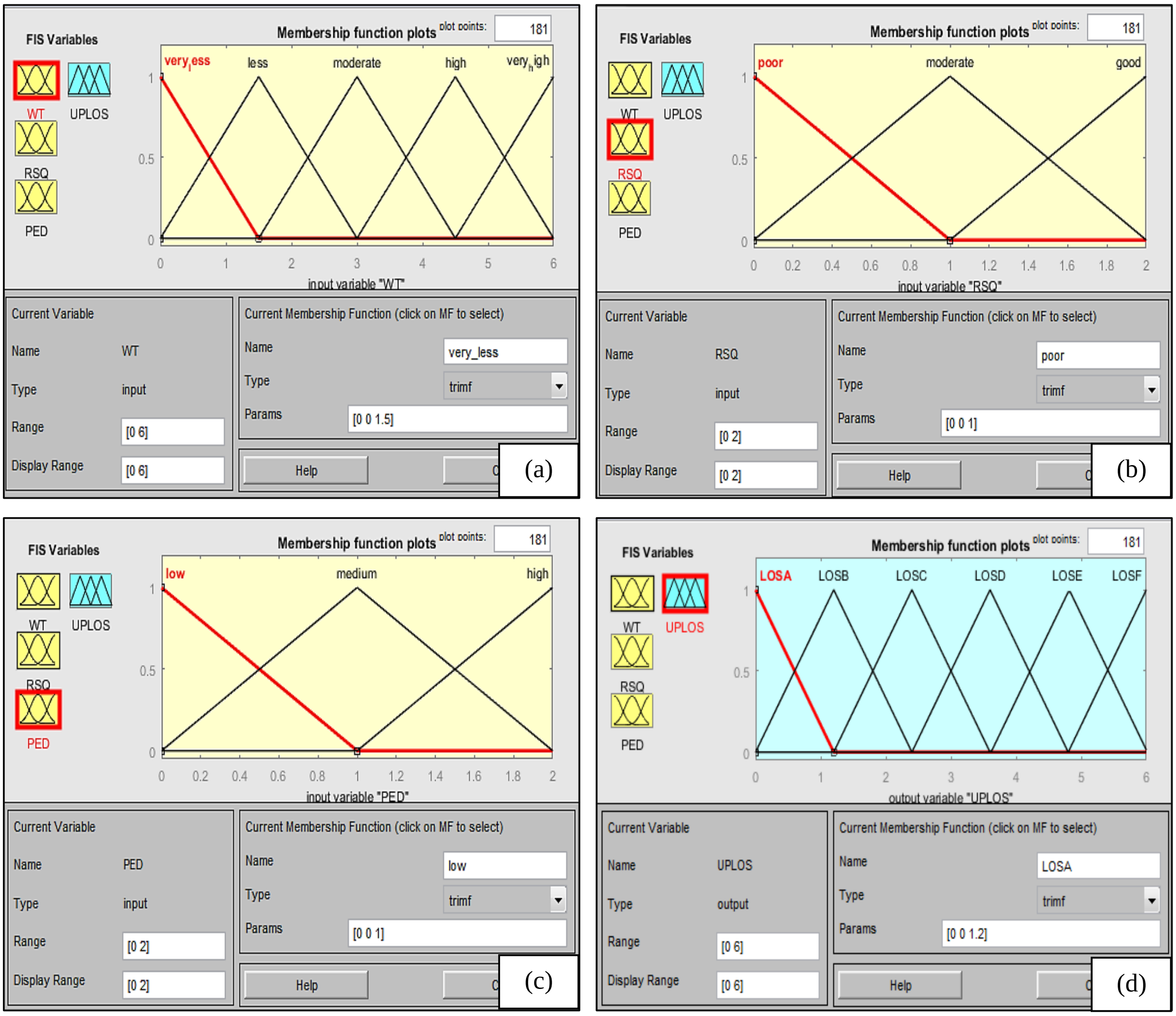

Fig. 1. (a) Membership function for waiting time (b) Membership function for road surface quality (c) Membership function for presence of pedestrians (d) Membership function for UPLOS.

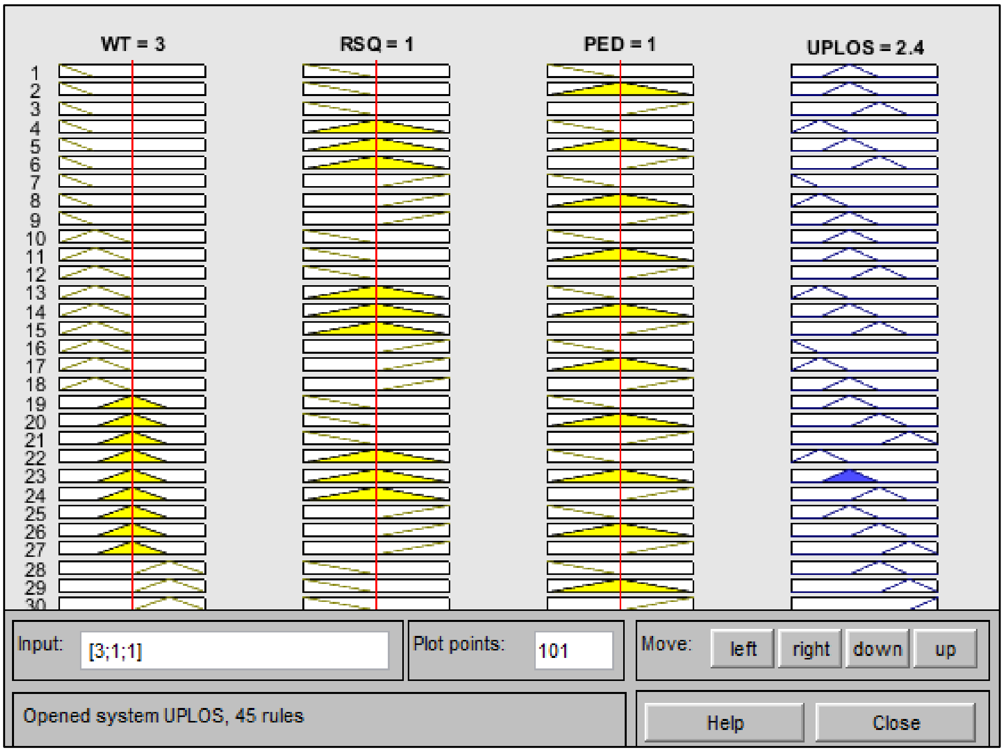

Fig. 2. Rule viewer window.

The surface viewer is used to view the dependency of the outputs on any one or two of the inputs-that is, it generates and plots an output surface map for the system. Figure 3 shows the surface viewer window. The first figure shows the effect of waiting time and road surface quality on the LOS keeping the presence of pedestrians as constant. The second figure shows the effect of waiting time and presence of pedestrians on the LOS keeping the road surface quality as constant.

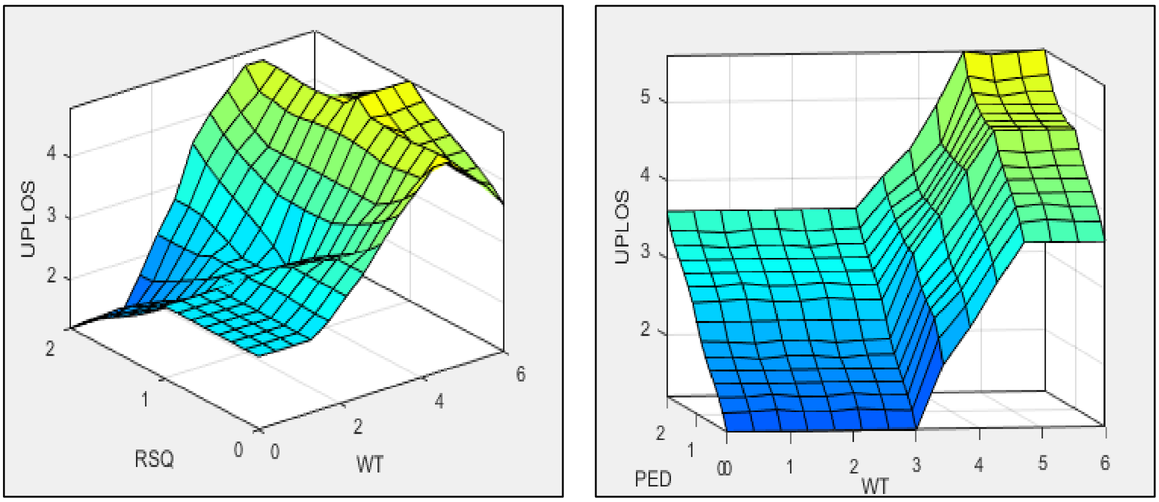

Fig. 3. Relation between the input and output variables.

Model Validation

The developed model is validated using the remaining 30% of collected data. The model validation results are represented in the form of a prediction-success table. It is a cross-classification between the observed LOS and the predicted LOS. Table 3 gives the results of the model validation. The observed share for LOS A is 2% whereas that for LOS C is 41%. LOS C has the highest percentage of predicted share. The sum of the diagonal elements of the prediction-success table gives the overall prediction success. For the developed model the overall prediction success rate is 76.4%. Hence, it can be concluded that the developed model accounts for the user perceptions of the level of service quite well in heterogeneous traffic condition.

Table 3. Prediction-success table.

Observed LOS	**Predicted LOS**						**Row Sum**	**Observed Share** (%)
	LOS A	**LOS B**	**LOS C**	**LOS D**	**LOS E**	**LOS F**		
LOS A	42	8	1	0	0	0	51	2
LOS B	82	366	99	36	0	0	583	23
LOS C	0	76	828	123	13	0	1040	41
LOS D	0	9	36	530	71	14	660	26
LOS E	0	0	2	12	106	7	127	5
LOS F	0	0	0	0	9	67	76	3
Column Sum	124	459	966	701	199	88	**2537**	
Predicted Share (%)	5	18	38	28	8	3		

Conclusions

Users' are the integral component of any transportation system. The ultimate goal of intersection design and traffic operations is to accommodate users' needs and provide them safe and comfortable service. The present study aims at modeling the user perceived LOS (UPLOS) at signalized intersection using fuzzy logic approach. The various determinants of users perceived LOS at signalized intersection are identified from the literature and incorporated in a questionnaire survey. The research contribution in this study is built on a massive user perception survey data collected from real-world setting. As the increase in the number of input variables lead to more complex model, only the most important determinant's of UPLOS are incorporated for the model development. Through an IS analysis, waiting time at the signalized intersection, road surface quality and presence of pedestrians are found to be the most important and least satisfied factors as the users are concerned.

For developing the fuzzy logic based UPLOS model, the input variable 'waiting time' is divided into five membership functions and the other two input variables 'road surface quality' and 'presence of pedestrians' are divided into three membership functions. The output variable, user perceived LOS is divided into six membership functions to be in compliance with the LOS categories proposed in HCM. All the variables are assigned with triangular membership function for simplicity. The fuzzy rules are generated from the training data and the model was calibrated. Using 30% of the collected data, the model has been validated. The results of prediction-success table indicates that the overall prediction success rate of the developed model is 76.4%.

It can be concluded that the developed model accounts for the user perceptions of level of service quite well in heterogeneous traffic condition. Incorporating users' perceptions into the signalized intersection LOS methodology may provide a more practically useful and theoretically sounder basis for signalized intersection design and traffic operations. Also, the consideration of the various factors that influence the users' perception as the performance measure would increase the likelihood of successful projects by better informing the transportation investment decisions.

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