European Transport \ Trasporti Europei (2022) Issue 89, Paper n° 1, ISSN 1825-3997

https://doi.org/10.48295/ET.2022.89.1

Modeling Level of Service of Urban Roads Based on Travelers' Perceptions

Jithin Raj[1*], P. Vedagiri[2]

[1]*Former Ph.D. Scholar, Indian Institute of Technology Bombay, Mumbai – 400076, India*
[2]*Professor, Indian Institute of Technology Bombay, Mumbai – 400076, India*

Abstract

This research investigates and models the level of service for urban roads based on travelers' perceptions. A video-based perception survey is utilized to collect the required perception data, in which the survey participants assessed the quality of operating conditions illustrated in the given video clips. The ratings stated by the study participants were statistically related to the corresponding traffic parameters associated with the video clips using a random-effects ordered probit modeling approach. The primary findings confirm that level of service was primarily dependent on average travel speed, as indicated by the significance of the measure of effectiveness known as the percent free-flow speed. Subsequently, a comprehensive exploratory analysis revealed that other traffic characteristics such as control delay, extra lanes, and proper medians also influenced the perception of service levels. Specific traveler characteristics like age, income and usage of particular vehicle classes also influenced the perception of the level of service on urban roads.

Keywords: Urban Roads, Level of Service, Traveler Perceptions, Random Effects Ordered Probit, Video-Based Perception Survey

1. Introduction

The information regarding service quality is inevitable for the planning, design, and operation of any traffic facility. The Level Of Service (LOS) concept, introduced in 1965 by the Highway Capacity Manual (HCM), is widely used to analyze and measure service quality. HCM (2010) defines LOS as the quantitative stratification of a performance measure or measures that represent the quality of service. The conventional practice defines six levels of service ranging from *A* to *F*, denoting best to worst service quality, respectively. Generally, LOS *A* represents the free-flow condition, *B* the reasonable free-flow condition, *C* the stable flow condition, *D* the approaching stable flow condition, *E* the unstable flow condition, and *F* the forced or break-down flow condition. Hence, LOS modeling usually signifies identifying suitable service measures and defining their thresholds corresponding to different service levels. The six service levels categorized by threshold values of service measures given by the latest version of HCM (2016) are often used for evaluating the LOS of different road facilities these days.

* Corresponding author: Jithin Raj (jithinraj437@gmail.com)

Urban road facilities fundamentally differ from highways or freeways due to fixed interruptions such as signalized intersections throughout the facility. HCM (2010) defines the urban street facility as the extended sections of collector or arterial streets that include the impacts of traffic signals or other traffic control along the street. On the contrary, freeways and their components operate under the purest form of uninterrupted flow, with controlled access and limited ramp locations (HCM, 2010). Similarly, highways operate under uninterrupted flow in long segments between points of fixed interruption. Hence the service measure used for the freeways and highways is density and speed, respectively, whereas average travel speed is the service measure for categorizing urban road service levels. The LOS thresholds based on travel speed defined by the HCMs are widely used for evaluating urban road LOS, which has been revised over time. Many studies have also attempted to model the LOS on urban roads, but most were conducted in homogeneous traffic (e.g., Brilon and Estel, 2010; Deshpande et al., 2010). Hence, due to the issues associated with transferability, a few countries have also defined their methodologies and thresholds for evaluating the service quality of urban roads. Indian Road Congress (IRC-106, 1990) guidelines and the Indian Highway Capacity Manual (Indo-HCM, 2017) are the two popular manuals developed to evaluate urban road LOS in Indian traffic conditions. The travel speed thresholds in these manuals are entirely different from that of HCMs. Limited studies have also been found in the Indian context to define the urban road level of service (e.g., Bhuyan and Rao, 2011; Manghat et al., 2017). Hence it is essential to note that LOS is a complex notion that varies with respect to facilities, location, and time and one such factor is the perception of service levels. So, the present study aims at modeling the urban road LOS from the travelers' perspective.

User perception has interested many researchers for the past few years. For example, Qin et al. (2018) analyzed the perceived effects of the public bike-and-ride on choice behavior. In contrast, Weber and Mouzakitis (2019) have found that the emotional experiences during driving depend on driving conditions and the type of road. Studies have also analyzed users' perceptions of taxi service quality (Askari et al., 2021), rider satisfaction with transit service (Zhang et al., 2017), and service quality from the perspective of bicyclists (Beura and Bhuyan, 2017). Hence, road users' perception is a vital aspect of traffic engineering and must be considered while analyzing urban road LOS. Even though researchers have added more details to the definition of LOS, travelers' satisfaction with service levels was not studied extensively (Flannery et al., 2005). But it is crucial to consider the travelers' perception of different service levels as they are the end-users of any traffic facility. Studies have also attempted to understand the gaps between users' expectations and their experience on roads. However, they mainly were conducted for the facilities such as freeways (Choocharukul et al., 2004; Washburn and Kirschner, 2006), highways (Papadimitriou et al., 2010), and signalized intersections (Lee et al., 2007; Fang and Pécheux, 2009; Zhang and Prevedouros, 2011). A few studies have also been found for the urban road LOS based on user perceptions under homogeneous traffic conditions (Flannery et al., 2005 and 2008; Dowling et al., 2008). Nevertheless, these models cannot be applied directly in mixed traffic conditions due to the multiple vehicle classes and frequent intersections along the urban roads. Hence, there is a need to understand the LOS of urban roads from travelers' perspectives under mixed traffic conditions.

Another practice that needs attention is using a single service measure to classify service quality. The users may perceive the quality of service based on multiple parameters, which must be verified while incorporating the perceptions into the LOS analysis. Few studies have also introduced, modified, and added other significant factors in addition to the commonly used service measure for a better definition of urban road LOS. Flannery et al. (2005) found that multiple factors were highly correlated with mean driver ratings, such as average speed, the presence of a median, and the presence of trees. A similar study by Flannery et al. (2008) developed models based on stops per mile, exclusive left-turn lanes, and the presence of trees. Dowling et al. (2008) developed a LOS model based on stops per mile and the proportion of intersections with left-turn lanes. Similarly, visibility of signs and signals, the timing of traffic signals, and the ability to maneuver the vehicle were also identified as significant factors in defining urban road LOS by Pécheux et al. (2014). HCM (2010) has also provided a separate methodology for finding traveler perception scores based on the factors, intersections with left-turn lanes, and spatial stop rate. Even though this score provides a valuable indication of performance from the traveler's perspective, it is entirely independent of the LOS determination methodology. Jena et al. (2018) analyzed the importance of nine variables influencing drivers' satisfaction on urban roads and found that the pavement condition index has the highest impact. Studies have recognized that users consider multiple factors in determining trip quality. So, the influence of various traffic characteristics on the urban road LOS under mixed traffic conditions must be verified.

Furthermore, perceptions may change due to the traveler's characteristics and traffic conditions (Choocharukul et al., 2004; Washburn and Kirschner, 2006). Although a few existing studies have analyzed various traffic-related variables in defining the perceived LOS of urban roads, the influence of traveler characteristics is yet to be acknowledged. Socio-demographic features may also have a considerable effect on such perceptions. Similarly, travel behavior is another potential factor that can alter the LOS perception. In addition, the travelers representing mixed traffic conditions can have different perceptions than homogeneous traffic. Therefore, this research examines the travelers' perceptions of the LOS on urban roads in relation to the traffic and traveler characteristics of mixed traffic conditions.

2. Methodology

The study intends to investigate the various factors underlying the travelers' perception of the LOS on urban roads by utilizing appropriate statistical modeling techniques. Hence, the two major challenges that need to be addressed are collecting realistic traveler perception data and modeling the LOS incorporating perceptions.

2.1 Traveler's perception

Interviewing is a standard method for collecting road user perceptions in the existing studies. The popular interviewing methods are the in-vehicle interview method (Pécheux et al., 2014), the roadside interview method (Papadimitriou et al., 2010), and cultural consensus analysis (Lee et al., 2007). Another method is the questionnaire survey which has different forms, such as the web-based survey (Zhang and Prevedouros, 2011) and the postal questionnaire (Soest et al., 2019). The video-based survey is also used to gather user perceptions in the laboratory by having the study participants evaluate the video clips of actual traffic scenarios (Choocharukul et al., 2004; Flannery et al., 2005 and 2008; Washburn and Kirschner, 2006; Dowling et al., 2008; Fang and Pecheux, 2009). As this type of survey is pre-informed, the chances of random ratings by the participants will be less than a simple roadside interview or questionnaire survey. At the same time, multiple video clips allow the participant to compare different operating conditions, which results in more realistic responses. Moreover, a video-based perception survey can generate more data than other techniques; therefore, it is deployed to collect the traveler perceptions in this study.

2.2 Modeling approach

Though intersections are present on urban roads, they are usually evaluated as mid-blocks in Indian traffic scenarios (Raj et al., 2022). According to HCM (2016), urban street segments are defined as a segment of roadway bounded by controlled intersections at either end that requires the street's traffic to slow or stop. A pilot study of the video-based perception survey deduced that segments between signalized intersections have varying segment lengths and could highly influence travelers' perceptions. Moreover, defining the segments between two signalized intersections is not practical when the signal density is high. Hence, despite the conventional practice, the study has defined urban roads as segments of fixed length, including multiple intersections, rather than segments of varying length between two signalized intersections. Besides, in this approach, travelers' perceptions are influenced by the factor, namely progression through intersections.

HCM (2016) has defined the urban road LOS based on the average travel speed, separately for different free-flow speeds. In contrast, HCM (2010), IRC-106 (1990), and Indo-HCM (2017) have a specific service measure known as percent free-flow speed (PFFS) that suits all the facilities irrespective of the free-flow speed associated. PFFS is defined as the representation of average travel speed in terms of the percentage of free-flow speed as given in Eq. (1). Hence the primary focus of the study is to model the travelers' perception of the urban road LOS concerning the service measure, PFFS. However, other traffic and traveler characteristics influencing travelers' perceptions are examined and modeled accordingly.

$$PFFS = \frac{Average\ Travel\ Speed}{Free\ Flow\ Speed} \times 100 \tag{1}$$

2.3 Random effects ordered probit

Several methods were implemented in the past for modeling perception data, such as logit models (Qin et al., 2018; Raj and Vedagiri, 2022), stepwise regression (Dowling et al., 2008), piecewise linear model (Papadimitriou et al., 2010), and ordered probit model (Kadali and Vedagiri, 2015; Raj and Vedagiri, 2020). Since the LOS categories are ordered in nature, i.e., LOS *A* better than LOS *B*, LOS *B* better than LOS *C*, and so on, the ordered probability approach is suited for the modeling purpose. Hence, compared to other modeling techniques, the ordered probit model was selected to analyze the discrete and ordered nature of the data. A standard ordered probit model considers all the ratings from the perception survey are independent of each other. More specifically, generated by either a single participant or completely different participants. However, in this study, the ratings were generated by multiple participants evaluating multiple video clips. The survey participants are associated with some unobserved characteristics and would have been reflected in evaluation video clips. Thus, the ratings given by a participant hold an unobserved individual random effect, which may lead to erroneous models if not accounted for in the analysis. Therefore, for this study, an advanced probit modeling, namely the random effects ordered probit model, is preferred for accurately modeling traveler perceptions. Studies have used this modeling when multiple participants generated the perception data (Choocharukul et al., 2004; Washburn and Kirschner, 2006). Random effects ordered probit is derived by defining an unobserved variable z, specified as a linear function for each observation, as shown in Eq. (2).

$$z_{jk} = \beta X_{jk} + \epsilon_{jk} + \varphi_j \tag{2}$$

Where z is a vector of the dependent variable (video clip ratings), X is a vector of independent variables determining the LOS perceptions, β is a vector of estimable parameters, ϵ is the random error term, φ is the individual random effect term associated with the individual participants, j is the participant identity, and k is the video clip identity. Using this equation, a latent variable, y_{jk} is defined as each participant's evaluation of the video clips (with LOS *A, B, C, D, E,* and *F* corresponding to y_{jk} = 0, 1, 2, 3, 4 and 5 respectively), as shown in Eq (3).

$$y_{jk} = 0 \quad if\ z_{jk} \le \mu_0, (LOS\ A) \tag{3a}$$
$$y_{jk} = 1 \quad if\ \mu_0 < z_{jk} \le \mu_1, (LOS\ B) \tag{3b}$$
$$y_{jk} = 2 \quad if\ \mu_1 < z_{jk} \le \mu_2, (LOS\ C) \tag{3c}$$
$$y_{jk} = 3 \quad if\ \mu_2 < z_{jk} \le \mu_3, (LOS\ D) \tag{3d}$$
$$y_{jk} = 4 \quad if\ \mu_3 < z_{jk} \le \mu_4, (LOS\ E) \tag{3e}$$
$$y_{jk} = 5 \quad if\ z_{jk} > \mu_4, (LOS\ F) \tag{3f}$$

The estimation problem then determines the probability that a traveler will select a particular rating for each clip. The resulting response category selection probabilities can be calculated as shown in Eq. (4). Here, μ_i and μ_{i-1} are the upper and lower threshold values for the i^{th} LOS category. $P(.)$ is the probability, and $\emptyset(.)$ is the cumulative normal distribution given by Eq. (5).

$$P(y_{jk} = 0) = \emptyset(\mu_0 - \beta X_{jk}) \tag{4a}$$
$$P(y_{jk} = 1) = \emptyset(\mu_1 - \beta X_{jk}) - \emptyset(\mu_0 - \beta X_{jk}) \tag{4b}$$
$$P(y_{jk} = 2) = \emptyset(\mu_2 - \beta X_{jk}) - \emptyset(\mu_1 - \beta X_{jk}) \tag{4c}$$
$$P(y_{jk} = 3) = \emptyset(\mu_3 - \beta X_{jk}) - \emptyset(\mu_2 - \beta X_{jk}) \tag{4d}$$
$$P(y_{jk} = 4) = \emptyset(\mu_4 - \beta X_{jk}) - \emptyset(\mu_3 - \beta X_{jk}) \tag{4e}$$
$$P(y_{jk} = 5) = 1 - \emptyset(\mu_4 - \beta X_{jk}) \tag{4f}$$
(4g)

$$\emptyset(u) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{u} e^{\frac{-1}{2}w^2} dw \tag{5}$$

These equations are solved using maximum likelihood procedures, and the coefficients, β_i, and thresholds, μ_i (5 thresholds for 6 LOS categories) can be estimated. NLOGIT 5.0, an econometric and statistical software package, is utilized for developing the random effects ordered probit models.

3. Data Collection

The study involves four types of data collection (i) Collection of video data for conducting the perception survey, (ii) Collection of perception data using the video-based perception survey, (iii) Collection of traffic characteristics, and (iv) Collection of traveler characteristics using questionnaire forms.

3.1 Videographic data from the field

The foremost requirement for conducting the video-based perception survey is the videographic data of urban roads from the travelers' viewpoint. A device, namely Video-Velocity-Box (Video V-Box) that can simultaneously give video and GPS (Global Positioning System) data, was employed. The advantage of using this device is that the output video and GPS data are synchronized, minimizing the manual error of combining both data. The VBox camera was installed on the front side of a test vehicle to obtain a view through the front windshield as the vehicle moved on the urban roads. The video V-Box output videos had a superimposed speedometer at the right bottom.

The study locations were selected on three urban roads in Mumbai city, India – (a) Jogeshwari Vikhroli Link Road (JVLR), (b) Swami Vivekananda Road (SVR), and (c) Lal Bahadur Shastri Road (LBS), having a length 10.6 km, 10.3 km, and 12.3 km respectively. The selected urban roads had varying free-flow speeds due to the variation in roadway width and the number of intersections in the stretch. JVLR had a three-lane divided roadway in one direction, whereas the other two had only two lanes. Round trips were made along the study sections, using the V-Box installed test vehicle, from 7 AM to 12 PM and 1 PM to 6 PM to collect data under different operating conditions. The survey was also conducted at a low volume condition (< 100 pcphpl, 2 AM to 5 AM) to find the free-flow speeds and was obtained as 60 km/h, 50 km/h, and 45 km/h for the roads JVLR, SVR, and LBS respectively. The collected video data were then used for conducting the video-based perception survey. The screenshot of sample videos collected using V-Box from the study sections is shown in Figure 1.

Figure 1: Output videos from Video-VBox

3.2 Perception data from travelers

Short video clips were generated from the video data, and the PFFS was measured for the video clips. The preliminary analysis found that longer video clips greater than 5 minutes could distract participants and affect their perceptions, resulting in random ratings. So the video clips were limited to a maximum of 5 minutes duration and trip length as 1 kilometer uniformly for all the clips. 18 video clips with different PFFS, six from each location representing a wide range of operating conditions, were identified for the perception survey.

The perception survey was carried out in numerous sessions in a meeting room by accommodating multiple participants for each session. The video clips were projected on a big screen to provide an unobstructed view similar to the front windshield of a traveling vehicle. The superimposed speedometer on the bottom of the video clips also helped the participants to sense urban road travel. The participants were provided with the basic knowledge of the LOS classifications before the sessions with the help of sample video clips. They were asked to indicate the ratings as excellent, very good, good, fair, poor, and very poor, corresponding to the six discrete categories of LOS *A, B, C, D, E,* and *F.* The participants were advised to review the clips based on factors that could affect their trip quality. The selected video clips were shown randomly to the participants, who were allowed to rate them immediately after viewing each clip. The number of clips shown in each session varied from 12 to 18, corresponding to a total duration of 30 to 45 minutes. 206 urban road travelers from the Indian cities Mumbai and Pune constituted the survey participants for the study. As the participants were selected from two different cities, the bias concerning the familiarity with the chosen urban road sections was eliminated. Figure 2 shows the frequency of travelers' ratings for the video clips.

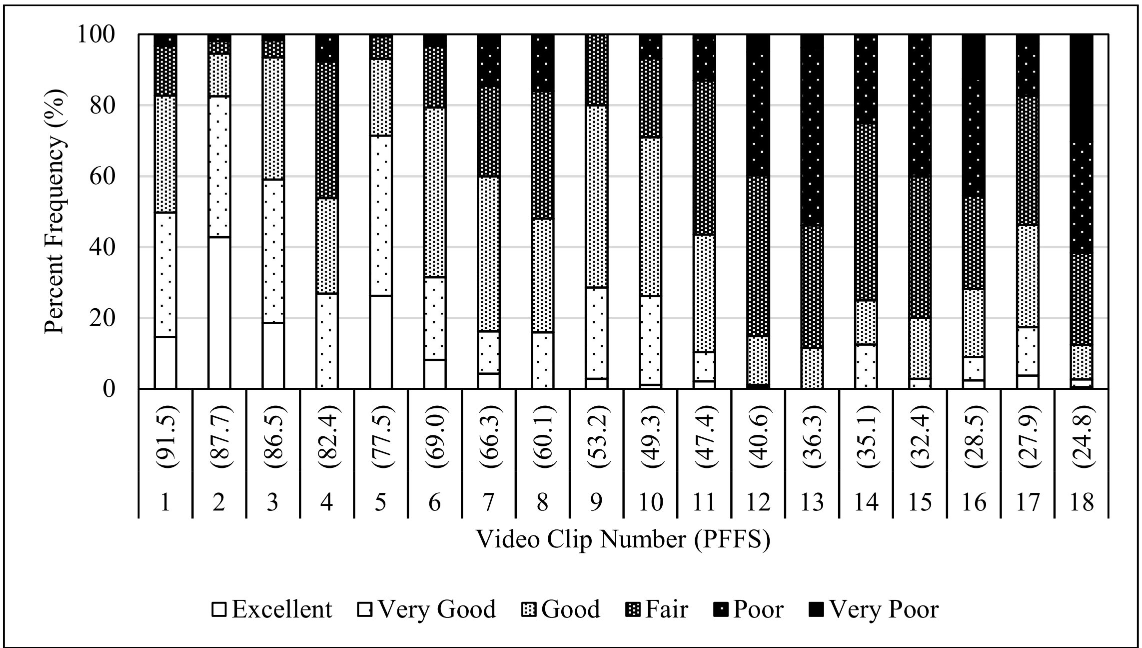


Figure 2: Percent frequency of travelers' ratings for the video clips

3.3 Traffic and traveler characteristics data

For modeling the LOS, traffic data was also required to be collected apart from the perception data. The traffic data obtained directly from the field and V-Box included mainly travel-related and geometric characteristics. The descriptive statistics of a few selected traffic variables are shown in Table 1. The ratings of the video clips were gathered from the participants by employing a questionnaire form. The same questionnaire form was utilized to collect the study participants' personal information like socio-economic and travel behavior characteristics, as shown in Table 2.

Table 1: Selected traffic characteristics and descriptive statistics

Variables		Description: Minimum	Maximum	Mean	SD
Continuous Variables	Carriageway width (m)	5.50	11.50	7.55	2.25
	Segment length (km)	0.91	1.04	0.98	0.04
	Average travel speed (km/h)	11.20	51.90	28.57	11.81
	Percent free-flow speed (%)	24.80	91.50	55.36	22.24
	Running time (s/km)	69.00	282.00	128.06	48.99
	Number of intersections (per km)	0.00	4.00	1.50	1.07
	Control delay (s/km)	0.00	122.00	20.94	32.51
	Traffic flow (pcphpl)	97.00	1109.00	690.00	310.18
	Percent of heavy vehicles (%)	1.35	17.86	7.15	5.15
Ordinal Variables	Presence of three lanes	Yes = 1; No = 0			
	Presence of proper median	Yes = 1; No = 0			
	Presence of curve/gradient	Yes = 1; No = 0			
	Presence of proper road markings	Yes = 1; No = 0			
	Roadside parking	High = 2; Moderate = 1; Less = 0			
	Pedestrian movement/crossing	High = 2; Moderate = 1; Less = 0			
	Pavement Condition	Good = 1; Not good = 0			
	Road Visibility	Good = 1; Not good = 0			
	Aesthetics and Landscapes	Good = 1; Not good = 0			

Table 2: Selected traveler characteristics and the corresponding percent shares

Characteristics		*Category 1*	*Category 2*	*Category 3*	*Category 4*	*Category 5*
Socio-economic	Gender	Male (72%)	Female (28%)	-	-	-
	Age[a]	Young (45%)	Middle (49%)	Old (6%)	-	-
	Education	Traffic Researchers (8%)	Traffic Engineers (14%)	Graduates (10%)	Undergraduates (30%)	Others (38%)
	Monthly Income[b]	Low (24%)	Moderate (64%)	High (10%)	Very High (2%)	-
Travel Behavior	Vehicle Class	Two-wheeler (57%)	Three-wheeler (16%)	Car (14%)	Bus (13%)	-
	Frequency of Travel	Frequently (42%)	Weekly (35%)	Occasionally (23%)	-	-
	Driving Experience[c]	None (12%)	Less (14%)	Moderate (44%)	High (30%)	-

Note: Values in parenthesis are the percentage share of the category; [a]Age in Years (Young: <30; Middle: 30-45; Old: >45). [b]Monthly Income in Thousand Indian Rupees (Low: <15; Moderate: 15-50; High: 50-100; Very High: >100). [c]Driving Experience in Years (None: 0; Less: 1-5; Moderate: 5-10; High: >10).

4. Development of perceived LOS models

The analysis explored the influence of different parameters in perceiving the LOS. So the dependent variable for the random effects ordered probit model is the traveler rating of video clips, and the explanatory variables are the different possible parameters that influence the perceptions. The video clip ratings from 166 participants (80% of total participants) were used to develop the models. The video clip ratings that were not logical were considered outliers, such as excellent ratings for highly congested conditions or poor ratings for free flow conditions. Three types of modeling approaches were attempted: (i) Based on PFFS (Model-1), (ii) Based on traffic characteristics (Model-2), and (iii) Based on traffic and traveler characteristics (Model-3). An extensive examination of the models and the significant variables is also done.

4.1 Model-1: LOS based on PFFS

The popular manuals have used a single service measure based on travel speed for defining urban road LOS. Hence, the first analysis explored how the travelers perceived the LOS concerning the service measure, PFFS, as the sole criteria. A correlation between PFFS and ratings can be visually observed in Figure 2, which was statistically modeled using the random effects ordered probit analysis. Hence, the dependent variable for the probit model is the traveler ratings of video clips, and the explanatory variable is the corresponding PFFS of the video clips. Table 3 shows the details of the developed models using the random-effects ordered probit model.

Table 3: Random effects ordered probit modeling of traveler ratings

Parameters	*Model-1*		*Model-2*		*Model-3*	
	Estimate	*t-statistic*	*Estimate*	*t-statistic*	*Estimate*	*t-statistic*
Constant, β_0	6.738	35.47	7.114	34.62	7.395	26.70
Traffic Characteristics:						
Percent Free-flow Speed, β_1	–0.073	–32.97	–0.073	–30.52	–0.073	–30.39
Control delay, β_2	–	–	0.004[a]	2.14	0.004[a]	2.15
Presence of proper median (Yes:1; No:0), β_3	–	–	–0.422	–4.64	–0.417	–4.58
Presence of three lanes (Yes:1; No:0), β_4	–	–	–0.339	–3.42	–0.346	–3.46
Traveler Characteristics:						
Traveler age > 30 (Yes:1; No:0), β_5	–	–	–	–	–0.316	–3.16
Monthly income < 50000 (Yes:1; No:0), β_6	–	–	–	–	–0.380[a]	–2.45
Two-wheeler traveler (Yes:1; No:0), β_7	–	–	–	–	0.310	2.88
Three-wheeler traveler (Yes:1; No:0), β_8	–	–	–	–	0.302[b]	1.74
Model Thresholds:						
Threshold 1, μ_0	0.000	0.00	0.000	0.00	0.000	0.00
Threshold 2, μ_1	1.628	19.56	1.635	19.33	1.640	19.15
Threshold 3, μ_2	2.818	32.71	2.905	33.33	2.911	32.99
Threshold 4, μ_3	3.963	38.25	4.192	39.49	4.197	39.68
Threshold 5, μ_4	5.383	44.23	5.766	46.05	5.764	45.68
Random Effects:						
Standard deviation of random effects, σ	0.479	11.03	0.521	11.38	0.473	10.86
Statistical Analysis:						
Number of samples, N	1583[c]		1583[c]		1583[c]	
Log-likelihood at zero, LL(0)	–2711.67		–2711.67		–2711.67	
Log-likelihood at convergence, LL(c)	–1871.93		–1798.84		–1788.06	
McFadden pseudo-R-Square, ρ^2	0.310		0.337		0.341	

[a]Significant at 5% level; [b]Significant at 10% level, All others significant at 1% level;
[c]Unbalanced panel data of 166 individuals.

The LOS score and criteria defined based on only PFFS are shown in Eq. (6).

$$LOS\ Score = 6.738 - 0.073\ PFFS \quad (6a)$$
$$LOS = A \quad if\ LOS\ Score \leq 0.000, \quad (6b)$$
$$LOS = B \quad if\ 0.000 < LOS\ Score \leq 1.628, \quad (6c)$$
$$LOS = C \quad if\ 1.628 < LOS\ Score \leq 2.818, \quad (6d)$$
$$LOS = D \quad if\ 2.818 < LOS\ Score \leq 3.963, \quad (6e)$$
$$LOS = E \quad if\ 3.963 < LOS\ Score \leq 5.383, \quad (6f)$$
$$LOS = F \quad if\ LOS\ Score > 5.383 \quad (6g)$$

The negative coefficient obtained for the PFFS and the corresponding thresholds indicates that the LOS score decreases with the increase of the explanatory variable. Consequently, the likelihood of a traveler perceiving a better LOS increases, which agrees with the logical relation between travel speed and service quality. This model can be conveyed more lucidly by converting the estimated model thresholds into thresholds of PFFS using Eq. (7a). Hence, the alternate form of the model in terms of PFFS thresholds is presented in Eq. (7b-g).

$$PFFS\ Threshold = \frac{\mu_i - \beta_0}{\beta_1} \tag{7a}$$

$$LOS = A \quad if\ PFFS > 92 \tag{7b}$$

$$LOS = B \quad if\ 70 < PFFS \leq 92 \tag{7c}$$

$$LOS = C \quad if\ 54 < PFFS \leq 70 \tag{7d}$$

$$LOS = D \quad if\ 38 < PFFS \leq 54 \tag{7e}$$

$$LOS = E \quad if\ 19 < PFFS \leq 38 \tag{7f}$$

$$LOS = F \quad if\ PFFS \leq 19 \tag{7g}$$

4.2. Model-2: LOS based on traffic characteristics

In the second analysis, additional traffic characteristics that can probably affect the perceived LOS were inspected. Statistical analysis was performed to ascertain which variables influenced the travelers' perception of the LOS. PFFS proved to be an essential variable that influenced the urban road LOS, supporting the results of Model-1. The traffic volume was frequently varying on the urban road segments due to the signalized intersections. Hence such parameters related to volume and percent composition did not influence the traveler perceptions and were insignificant in the modeling. Besides PFFS, three additional variables were found to be significant in the ordered probit modeling. These variables are control delay (CD), presence of three lanes (TL), presence of proper median (PM). The LOS model developed based on traffic characteristics is shown in Eq. (8).

$$LOS\ Score = 7.114 - 0.073\ \text{PFFS} + 0.004\ \text{CD} - 0.422\ \text{PM} - 0.339\ \text{TL} \tag{8a}$$

$$LOS = A \quad if\ LOS\ Score \leq 0.000, \tag{8b}$$

$$LOS = B \quad if\ 0.000 < LOS\ Score \leq 1.628, \tag{8c}$$

$$LOS = C \quad if\ 1.628 < LOS\ Score \leq 2.818, \tag{8d}$$

$$LOS = D \quad if\ 2.818 < LOS\ Score \leq 3.963, \tag{8e}$$

$$LOS = E \quad if\ 3.963 < LOS\ Score \leq 5.383, \tag{8f}$$

$$LOS = F \quad if\ LOS\ Score > 5.383 \tag{8g}$$

4.3. Model-3: LOS based on traffic and traveler characteristics

The third analysis incorporated additional traffic and traveler characteristics along with the PFFS to predict the perceived LOS. The traveler characteristics were defined as dummy variables and were assigned an ordinal value 1 (0 otherwise) corresponding to the subgroups to which the participants belonged. As a result, apart from Model-2 variables, the third model identified travelers with more than 30 years of age (AG), monthly income less than 50000 Indian rupees (MI), two-wheeler travelers (TW), and three-wheeler travelers (ThW) as the significant influencing variables for the LOS predictions. The developed model is shown in Eq. (9).

$$LOS\ Score = 7.395 - 0.073\ PFFS + 0.004\ CD - 0.417\ PM - 0.346\ TL - 0.316\ AG - 0.380\ MI + 0.310\ TW + 0.302\ ThW \tag{9a}$$

$$LOS = A \qquad if\ LOS\ Score \leq 0.000, \tag{9b}$$
$$LOS = B \qquad if\ 0.000 < LOS\ Score \leq 1.628, \tag{9c}$$
$$LOS = C \qquad if\ 1.628 < LOS\ Score \leq 2.818, \tag{9d}$$
$$LOS = D \qquad if\ 2.818 < LOS\ Score \leq 3.963, \tag{9e}$$
$$LOS = E \qquad if\ 3.963 < LOS\ Score \leq 5.383, \tag{9f}$$
$$LOS = F \qquad if\ LOS\ Score > 5.383 \tag{9g}$$

Since the third model identified the vehicle classes, namely two-wheelers and three-wheelers, as significant influent factors, an in-depth analysis of different vehicle class travelers' perceptions of PFFS was also carried out individually. Table 4 shows the ordered probit models and the PFFS thresholds, based on Eq. (7a) for each LOS category concerning different vehicle classes.

Table 4: Random effects ordered probit models for different vehicle classes

Parameters	*Model-4 (TW)*	*Model-5 (ThW)*	*Model-6 (Car)*	*Model-7 (Bus)*
Constant, β_0	6.892	7.312	6.062	6.430
Percent Free-flow Speed, β_1	–0.074	–0.077	–0.067	–0.072
Model Thresholds:				
Threshold 1, μ_0	0.000 (93)	0.000 (95)	0.000 (90)	0.000 (89)
Threshold 2, μ_1	1.658 (71)	1.760 (72)	1.312 (71)	1.846 (64)
Threshold 3, μ_2	2.881 (54)	3.052 (55)	2.386 (55)	2.958 (48)
Threshold 4, μ_3	4.021 (39)	4.326 (39)	3.642 (39)	3.731 (37)
Threshold 5, μ_4	5.417 (20)	5.774 (20)	4.982 (20)	5.352 (15)
Random Effects:				
Standard deviation of random effects, σ	0.490	0.315	0.459	0.460
Statistical Analysis:				
Number of samples, N	863[a]	267[b]	253[b]	200[d]
Log-likelihood at zero, LL(0)	–1478.641	–449.015	–433.278	–329.768
Log-likelihood at convergence, LL(c)	–1017.405	–302.821	–311.366	–226.089
McFadden pseudo-R-Square, ρ^2	0.312	0.326	0.281	0.316

Note: Values in parenthesis are PFFS thresholds; All coefficients are significant at 1% level; TW is Two Wheeler, ThW is Three Wheeler; Unbalanced panel data of [a]94, [b]24, [c]26, [d]22 participants.

5. Statistical analysis of the developed models

The statistical analysis focused on the following aspects: (i) Significance of models and variables, (ii) Marginal effects of model variables, and (iii) Validation of the models.

5.1. Significance of models and model variables

The perception data in this study is ordered and discrete; hence an ordered probabilistic approach is employed for modeling. According to Chen and Tsurumi (2010), if the data follows a leptokurtic distribution (kurtosis > 3), a logit model may explain the data better than the probit model, whereas the probit model may better explain the data if it follows platykurtic distribution (kurtosis < 3). The kurtosis of the perception data in the current analysis is measured as -0.91, which justifies using the probit model over a logit model. Another aspect of the analysis is the choice between a standard probit model and a random-effects probit modeling. The significance of the estimate, standard deviation (σ) of the random effects in the models, confirms the usage of a random-effects ordered probit model instead of a standard probit model. Hence, the developed models based on random-effects ordered probit in the present study are more efficient in controlling the unobserved heterogeneity associated with the perception.

The goodness of fit of the developed models is assessed using log-likelihood statistics. The high values of log-likelihood statistics claim the statistical significance of the models. Furthermore, McFadden pseudo-R-square (ρ^2) values were also estimated using Eq. (10) and obtained between 0.28 and 0.34. The ρ^2 values in the range of 0.2-0.4 indicate a good fit for the ordered probit models (McFadden, 1979). The estimated coefficients and thresholds of all the models were also statistically significant as implied by the p-values. Compared to the magnitude of coefficients, t-statistic is reasonably higher, suggesting minor standard error for the estimates, signifying a good closeness of observations with the fitted values. Hence, the corresponding t-statistic of the estimated parameters proved the importance of variables and the significance of thresholds.

$$\rho^2 = 1 - \frac{LL(C)}{LL(0)} \tag{10}$$

5.2 Marginal effects of model variables

The marginal effect explains the impact of the unit change of an explanatory variable on the probability of each perceived LOS category, while all other variables are held constant. The marginal effects calculated for each variable at different LOS categories for the three models as per Eq. (11) are shown in Table 5.

$$ME = \begin{cases} \dfrac{\partial P(y_{jk} = i)}{\partial X_{jk}} = [\emptyset(\mu_i - \beta X_{jk}) - \emptyset(\mu_{i-1} - \beta X_{jk})]\beta, for\ continuous\ variables \\ P(y_{jk} = i | X_{jk} = 1) - P(y_{jk} = i | X_{jk} = 0), for\ dummy\ variables \end{cases} \tag{11}$$

Table 5: Marginal effects of model variables

Model	*Variables*	*LOS A*	*LOS B*	*LOS C*	*LOS D*	*LOS E*	*LOS F*
Model-1	Percent free flow speed	0.0025	0.0180	0.0040	–0.0147	–0.0091	–0.0007
Model-2	Percent free flow speed	0.0021	0.0167	0.0055	–0.0157	–0.0082	–0.0004
	Control delay	–0.0001	–0.0009	–0.0003	0.0009	0.0004	0.0000
	Presence of proper median	0.0123	0.0964	0.0319	–0.0898	–0.0482	–0.0025
	Presence of three lane road	0.0112	0.0803	0.0191	-0.0735	-0.0354	-0.0017
Model-3	Percent free flow speed	0.0019	0.0170	0.0059	–0.0162	–0.0081	–0.0004
	Control delay	–0.0001	–0.0009	–0.0003	0.0009	0.0004	0.0000
	Presence of proper median	0.0110	0.0966	0.0339	–0.0920	–0.0472	–0.0023
	Presence of three-lane road	0.0105	0.0834	0.0210	–0.0777	–0.0356	–0.0015
	Traveler age > 30 years	0.0084	0.0736	0.0252	–0.0701	–0.0353	–0.0017
	Monthly income < Rs. 50000	0.0074	0.0803	0.0458	–0.0795	–0.0510	–0.0029
	Two-wheeler traveler	–0.0084	–0.0728	–0.0236	0.0691	0.0341	0.0016
	Three-wheeler traveler	–0.0065	–0.0660	–0.0327[a]	0.0647	0.0383[a]	0.0020[a]

[a]Not significant at 10% level; All others are statistically significant.

With a unit increase of PFFS in Model-1, the probability of perceiving the LOS *A, B,* and *C* increases by 0.25%, 1.80%, and 0.40%, respectively, whereas the probability of perceiving the LOS *D, E,* and *F* decreases by 1.47%, 0.91%, and 0.07% respectively. The interpretation of the model estimates is that a positive parameter means an increase in the variable gives a higher probability that a worse LOS will be perceived, whereas a negative parameter corresponds to a higher likelihood of perceiving a better LOS.

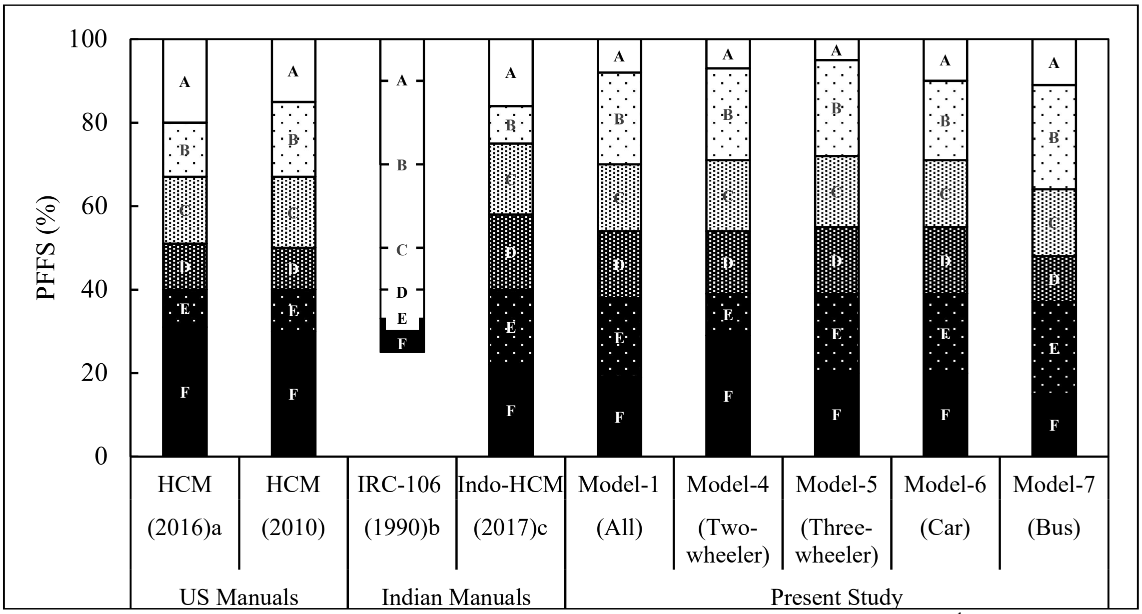
5.3. Validation of the models

The models were validated with additional perception data (responses from 20% of participants), and the performances were compared. The LOS was predicted using the developed models and was compared with the actual perceived LOS. The numbers of the actual and predicted LOS were tabulated for all the levels of service categories. The overall success prediction is the percent of correct LOS predictions and was obtained as 68.9%, 77.3%, and 78.5% for Model-1, Model-2, and Model-3, respectively. Even though the success prediction rate of the developed models is not excellent, it is found to be quite reasonable, considering the randomness associated with the travelers and the ratings. However, it is revealed that the traveler perceptions were very lightly represented in the existing manuals and codes, as implied by the success predictions. The rate of successful prediction of the existing manuals using the same validation data was found to be 37.4%, 33.8%, 36.5%, and 29.9%, respectively, for IRC-106 (1990), Indo-HCM (2017), HCM (2010), and HCM (2016). Hence, from the validation, it can be stated that the travelers' perceptions were well represented by the developed models.

6. Discussion and Conclusions

This study performed a comprehensive analysis to investigate the travelers' perception of urban road LOS. This was achieved using the responses collected by a video-based perception survey, modeled using random-effects ordered probit, and has resulted in three models. The first one is a quick and straightforward model that determines the LOS only with PFFS. The methodological approach of using service measures based on the travel speed is conventionally adopted for defining the urban road LOS. Hence, further analysis has led to the development of the univariate model with PFFS as the only service measure. Presumably, the preliminary findings suggested that the travelers perceived the urban road LOS primarily in the light of the traveling speed. The statistical significance of this parameter in the model indicates that it is the most appropriate service measure for defining urban road LOS based on perceptions.

A comparison between the Model-1 and the thresholds defined by existing manuals is also carried out, as shown in Figure 3. The current manuals have defined the LOS as *A* when the average travel speed exceeds 80 percent of the free-flow speed, whereas the corresponding threshold in Model-1 was obtained as 92. Similarly, when the average travel speed is less than 30 percent of the free-flow speed, it corresponds to the LOS *F* in the manuals. However, the developed model based on traveler perceptions suggests a PFFS of 19 for defining the service level as LOS *F*. The other estimated thresholds were comparable with the existing thresholds. In general, the comparison suggests that the perception-based thresholds have notable dissimilarities with the thresholds defined in the existing manuals, particularly for categories LOS *A* and *F*. This is because the manuals have not included traveler perceptions while developing the LOS models. The broad conclusion that can be drawn here is that urban road travelers in mixed traffic have a higher tolerance for congested conditions and a lower willingness to accept the free flow conditions than speculated. This variation explained an interesting observation about the reduction of ranges for LOS *A* and *F* when the traveler perceptions are incorporated. The disaggregated analysis with respect to different vehicle classes also showed a significant variation in the travel speed perceptions.



[a]HCM (2016) defines LOS based on travel speed, converted to average equivalent PFFS; [b]IRC-106 (1990) defines typical PFFS values instead of range; [c]Indo-HCM (2017) defines LOS for midblock.

Figure 3: Comparison of LOS thresholds of existing manuals and developed models

Though the assumption that the relation between traveler perceptions and average travel speed is proved valid, the analysis explored various other traffic characteristics in the perception of LOS of urban roads. These influencing variables were identified as control delay, the presence of three lanes, and the presence of proper medians. Each of these parameters had its instinctive signs that can be explained with the help of marginal effects. Even though control delay had comparatively lesser marginal effects, it was significant in the LOS predictions. The low marginal effect is due to the representation of variable in sec/km, as the unit increase in control delay cannot change the service quality significantly. The primary variable, PFFS, provides only indirect information on the total travel time, but the variable, control delay, indicates travelers' tolerance at the signalized intersections. The probability of a traveler giving a better service rating to a three-lane road compared to a two-lane urban road can be explained by the variable presence of a three-lane road. The marginal effects for these variables were very high, which justifies the inclusion of this variable in the model. The lesser maneuvering space available for travelers on a two-lane carriageway would have resulted in better ratings for three-lane urban roads. In addition, travelers use the unauthorized openings on the median of urban roads for taking u-turns or moving to minor approach roads, which often obstruct the free movement of the vehicles. Hence, another variable, the presence of proper median, i.e., without any unauthorized openings, is also highly influential in the perception of the LOS. The marginal effects of both these variables for the LOS *B* and *D* were obtained as high as 8-10%.

The characteristics of travelers such as age, income, and usage of two-wheelers or three-wheelers also affected service perceptions. The middle-aged and old travelers were likely to choose better service quality because they would prefer to travel at comparatively slower speeds than young travelers. According to marginal effects, such groups have 0.84%, 7.36%, and 2.52% higher probability of perceiving LOS *A, B, C,* respectively, and are less likely to perceive LOS *D, E, F* by 7.01%, 3.53%, and 0.17% respectively. Also, travelers with lower income mostly use public transport with frequent stops during their trip; hence this category is likely to give better ratings. The marginal effects of the variable are between 1% to 8% for LOS *A* to *C*, whereas -8% to 0% for LOS *D* to *F*. The two-wheelers and three-wheelers are smaller in size and usually use smaller gaps in the roadway for moving forward in congested conditions. Hence, travelers on such vehicles do not prefer to stop for even a smaller time interval and are likely to choose worse ratings. The PFFS thresholds of these vehicle classes were comparatively higher, as shown in Figure 3, which is in line with the significance of these vehicle classes in model-3. The corresponding marginal effects of these variables for LOS *A* to *C* were -7% to -1%. In contrast, it is 0% to 7% for LOS *D* to *F*. Hence it can be inferred that specific socio-economic and travel behavior characteristics also influence service level perceptions and must be considered while defining the LOS.

The practical application of the developed models is that urban roads can be evaluated from travelers' points of view. This will permit transportation engineers and planners to understand the requirements of travelers and allocate transportation resources more efficiently. Moreover, compared to the PFFS-based model, the multivariate models have performed better in various dimensions, such as explaining perceptions, traffic and traveler characteristics, and predictive performance. These novel models have provided valuable inferences such as additional traffic and personal factors, which allows transportation professionals to evaluate urban roads based on multiple parameters along with the conventional measure of travel speed. However, since the traffic variables involved in these models can be easily collected compared to traveler variables, the model based on only traffic characteristics may be preferred for quick applications. On the contrary, the model based on socio-economic and travel behavior factors would be too laborious but can be considered for precise evaluation of urban road LOS.

The limitations of the study are as follows. The video-based perception survey does not provide exact traveling conditions such as safety or comfort to the survey participants. Also, perceptions may differ depending on immediate past exposure to video clips. Secondly, the video data was collected only from roads in Mumbai city, and most of the responses were from male travelers. Expansion of data samples can result in better modeling of perceived urban road LOS. Despite these limitations, the study has contributed some meaningful insights into the complex relationship between traveler perceptions and the LOS of urban roads. As travelers can better appraise a trip's basic needs, the traveling population's cultural consensus on service measures should be recognized. It helps transportation professionals to consider these needs while designing urban roads and implement proper management measures for efficient operation. A better knowledge of service quality from travelers' perceptions also helps the practitioners make effective decisions about allocating investments and resources. Further, the identified service measures may help to improve the existing guidelines for evaluating urban roads. Ultimately, the approach and the analysis presented in the study can serve as conceptual inputs for understanding the traveler's perceptions of urban roads. In addition, the study implications can be utilized for evaluating LOS not only in Indian scenarios but also in similar traffic environments with mixed traffic conditions.

References

Askari, S., Peiravian, F., Tilahun, N., Baseri, Y. (2021) "Determinants of User's Perceived Taxi Service Quality in the Context of a Developing Country", *Transportation Letters* 13(2), pp. 125–137.

Beura, S.K., Bhuyan, P.K. (2017) “Development of A Bicycle Level of Service Model for Urban Street Segments in Mid-Sized Cities Carrying Heterogeneous Traffic: A Functional Networks Approach”, *Journal of Traffic and Transportation Engineering* 4(6), pp. 503-521.

Bhuyan, P.K., Rao, K.V.K. (2011) “Defining Level of Service Criteria of Urban Streets in Indian context”, *European Transport|Trasporti* Europei 49, pp. 38-52.

Brilon, W., Estel, A. (2010) “Differentiated Analysis of Level of Service F within the German Highway Capacity Manual”, *Transportation Research Record: Journal of Transportation Research Board* 2173, pp. 36-44.

Central Road Research Institute (CRRI). (20170 *Indian Highway Capacity Manual (Indo-HCM)*, CSIR, New Delhi.

Chen, G., Tsurumi, H.2 (2010) “Probit and Logit Model Selection”, *Communications in Statistics– Theory and Methods* 40(1), pp. 159–175.

Choocharukul, K., Sinha, K.C., Mannering, F.L. (2004) “User Perceptions and Engineering Definitions of Highway Level of Service: An Exploratory Statistical Comparison”, *Transportation Research Part A: Policy and Practice* 38, pp. 677-689.

Deshpande, R., Gartner, N.H., Zarillo, ML (2010) “Urban Street Performance: Level of Service and Quality of Progression Analysis”, *Transportation Research Record: Journal of Transportation Research Board* 2173, pp. 57-63.

Dowling, R., Flannery, A., Landis, B., Petritsch, T., Rouphail, N., Ryus, P. (2008) “Multimodal Level of Service for Urban Streets”, *Transportation Research Record: Journal of Transportation Research Board* 2071, pp. 1-7.

Fang, F.C., Pecheux, K.K. (2009) “Fuzzy Data Mining Approach for Quantifying Signalized Intersection Level of Services based on User Perceptions”, *Journal of Transportation Engineering* 135(6), pp. 349-358.

Flannery, A., Wochinger, K., Martin, A. (2005) “Driver Assessment of Service Quality on Urban Streets”, *Transportation Research Record: Journal of Transportation Research Board* 1920, pp. 25-31.

Flannery, A., Rouphail, N., Reinke, D. (2008) “Analysis and Modeling of Automobile Users’ Perceptions of Quality of Service on Urban Streets”, *Transportation Research Record: Journal of Transportation Research Board* 2071, pp. 26-34.

Indian Road Congress (IRC). (1990) *IRC-106: Guidelines for Capacity of Urban Roads in Plain Areas,* IRC, New Delhi.

Jena, S., Chakraborty, A., Bhuyan, P.K. (2018) “Performance Assessment of Urban Streets Addressing Improvement Issues for Automobile Mode of Transport”, *Transportation Research Record: Journal of Transportation Research Board* 2672 (45), pp. 232-241.

Kadali, B.R., Vedagiri, P. (2015) “Evaluation of Pedestrian Crosswalk Level of Service (LOS) in Perspective of Type of Land-Use”, *Transportation Research Part A: Policy and Practice* 73, pp. 113-124.

Lee, D., Kim, T., Pietrucha, M.T. (2007) “Incorporation of Transportation User Perception into Evaluation of Service Quality of Signalized Intersections”, *Transportation Research Record: Journal of Transportation Research Board* 2027, pp. 9-18.

Manghat, D., Aswathy, K.V., Krishnamurthy, K. (2017) “Automobile Level of Service Criteria for Two-Lane Undivided Heterogeneous Urban Corridors”, *European Transport / Trasporti Europei* 63(9), pp. 1-13.

McFadden D. (1979) "Quantitative Methods for Analyzing Travel Behaviour of Individuals: Some Recent Developments", *Behavior Travel Modeling*, Croom Helm: London.

Papadimitriou, E., Mylona, V., Golias, J. (2010) "Perceived Level of Service, Driver, and Traffic Characteristics: Piecewise Linear Model", *Journal of Transportation Engineering* 136(10), pp. 887–894.

Pécheux, K.K., Flannery, A., Wochinger, K., Rephlo, J., Lappin, J. (2014) "Automobile Drivers' Perceptions of Service Quality on Urban Streets", *Transportation Research Record: Journal of Transportation Research Board* 1883, pp. 167-175.

Qin, H., Gao, J., Kluger, R., Wu, Y. (2018). "Effects of Perception on Public Bike-and-Ride: A Survey under Complex, Multifactor Mode-choice Scenarios", *Transportation Research Part F: Traffic Psychology and Behavior* 54, pp. 264-275.

Raj, J., Vedagiri, P. (2020) "Evaluation of Travelers' Perception of Urban Road Level of Service under Mixed Traffic Conditions", Presented at *99th Annual Meeting of the Transportation Research Board* 20–02128, Washington, DC.

Raj, J., Vedagiri, P. (2022) "Evaluation of Perception and Nonperception based Approaches for Modeling Urban Road Level of Service", *Journal of The Institution of Engineers (India): Series A* 103(2), pp. 467-480. doi:10.1007/s40030-021-00602-4

Raj, J., Vedagiri, P., Rao, K.V.K. (2022) "Estimation of PCU Values for Urban Roads by Considering the Effect of Signalized Intersections under Mixed Traffic Conditions", *European Transport|Trasporti Europei* 86(6), pp. 1-17. doi: 10.48295/ET.2022.86.6

Soest, D., Tight, M.R., Rogers, C.D.F. (2019) "Exploring Transport Perceptions Across Urban Areas Using Free Associations", *Transportation Research Part F: Traffic Psychology and Behavior* 65, pp. 316-333.

Transportation Research Board (TRB). (2010) *Highway Capacity Manual (HCM) – Volume 3: Interrupted Flow*, TRB, Washington, DC.

Transportation Research Board (TRB). (2016) *NCHRP Report 825: Planning and Preliminary Engineering Applications Guide to the HCM (2016)*, Washington, DC.

Washburn, S.S., Kirschner, D.S. (2006) "Rural Freeway Level of Service Based on Traveler Perception", *Transportation Research Record: Journal of Transportation Research Board* 1988, pp. 31-37.

Weber, M., Mouzakitis, A. (2019) "Investigation of the Dependency of the Drivers' Emotional Experience on Different Road Types and Driving Conditions", *Transportation Research Part F: Traffic Psychology and Behavior* 65, pp. 107-120.

Zhang, C., Cao, X., Nagpure, A., Agarwal, S. (2017) "Exploring Rider Satisfaction with Transit Service in Indore, India: An Application of the Three-Factor Theory", *Transportation Letters* 11(8), pp. 469-477.

Zhang, L., Prevedouros, P.D. (2011) "User Perceptions of Signalised Intersection Level of Service Using Fuzzy Logic", *Transportmetrica* 7(4), pp. 279-296.

Acknowledgments

The authors acknowledge the following who contributed their time by participating in the video-based perception and questionnaire survey: (i) Students, staff, and workers in and around IIT Bombay, Mumbai, (ii) Prof. Sekhar Babu and engineering students of College of Military Engineering, Pune, and (iii) Traffic engineers of Pimpri-Chinchwad Municipal Corporation, Pune.