European Transport \ Trasporti Europei (2024) Issue 100, Paper n° 4, ISSN 1825-3997

https://doi.org/10.48295/ET.2024.100.4

Modeling Overall Level of Satisfaction with Sidewalks outside Metro Terminals: A User-Centric Approach

Lalitha Sree Chintakayala[1*], C.S.R.K Prasad[2]

[1] *Research Scholar, Department of Civil Engineering, National Institute of Technology, Warangal, India.*
[2] *Professor, Department of Civil Engineering, National Institute of Technology, Warangal, India.*

Abstract

This study addresses the gap in integrating subjective pedestrian satisfaction with sidewalks and the need for micro-level assessments near metro terminals to enhance first- and last-mile connectivity. Thus, it models the Overall Level of Satisfaction (OLS) with sidewalks around metro stations by combining user perceptions with traditional assessment variables. Data was collected through user rating surveys, where respondents evaluated sidewalk characteristics. The data was split into training and testing data (75:25). An Ordinal Logistic Regression (OLR) model was developed and analysed the relationship between physical and user characteristics with OLS. Key findings indicate that Surface Condition, Width, Continuity, Walking Environment, Safety, Security and Comfort positively influence OLS, while Obstructions, Vehicular Conflict and Encroachments negatively impact it. The McFadden pseudo-R-square (ρ^2) value of 0.235 shows that the model explains 23.5% of the variance in OLS, demonstrating strong explanatory power and a good fit to the data.

Keywords: Sidewalks, Overall Level of Satisfaction (OLS), User Perceptions, Ordinal Logistic Regression (OLR) Model.

1. Introduction

Urban infrastructure is essential for improving the quality of life for urban dwellers. Sidewalks outside transit terminals play a crucial role in facilitating pedestrian mobility and connecting commuters to the transit system. Assessing the Overall Level of Satisfaction (OLS) of commuters with sidewalks from a user perspective is crucial for analysing and enhancing the pedestrian experience. This, sequentially can encourage the utilization of transit services and support sustainable urban mobility. Consequently, sidewalks serve as essential elements of urban landscape, impacting safety, accessibility and visual attractiveness of city, rather than merely functioning as walkways. Well-constructed sidewalks of superior quality have the potential to stimulate walking, alleviate traffic congestion and enhance public health by fostering physical exercise. Conversely, sidewalks that are inadequately maintained or poorly designed may deter pedestrians, pose safety risks and negatively impact the overall walking experience.

Sidewalks in developed countries are wider, well-maintained and accessible, with clear signage and safety features. In contrast, sidewalks in developing countries like India,

* Corresponding author: Lalitha Sree Chintakayala (lc712005@student.nitw.ac.in)

particularly in cities like Hyderabad are often narrow, poorly maintained and encroached upon, lacking essential safety and accessibility elements, posing challenges for pedestrians. Thus, the main objective of this study is to develop a model to assess OLS of pedestrians using sidewalks outside metro terminals of the Hyderabad Metro, Telangana State, India. This involves evaluating sidewalk conditions, incorporating user perceptions, identifying key factors and applying OLR for modeling, providing insights for improving pedestrian infrastructure. The novelty of this work lies in its user-centric approach to evaluate the OLS of sidewalks, specifically around metro terminal stations. Unlike traditional assessments that often focus on physical attributes and design aspects of different elements, this study integrates the user perceptions and satisfaction of daily commuters, providing a holistic view of the current state of sidewalks around metro terminals and identify areas for improvement. By combining comprehensive surveys, field observations and analysis of both physical and user characteristics, the study offers a unique model that identifies critical factors influencing pedestrian satisfaction. This approach not only highlights the importance of user satisfaction in urban infrastructure evaluation but also offers actionable insights for urban planners and policy makers for improving sidewalk design and maintenance, fostering greater walking participation and enhancing urban mobility.

2. Literature study

Ample studies accomplished by researchers globally have illustrated that assessing sidewalk satisfaction is vital for enhancing pedestrian experiences and promoting the use of public transportation systems. Since several decades, the significance of well-designed and properly maintained sidewalks has been recognized by urban planners and researchers are consistently exploring various factors that influence pedestrian satisfaction.

Wang et al. (2012) employed Factor Analysis and Path Model to study the physical characteristics of sidewalks. They found that perceptions had a greater influence on satisfaction than the physical elements of the sidewalks. A significant gap identified was the lack of consideration of user characteristics in their analysis. Kwon et al. (2016) used the Multi-Modal Level of Service (MMLOS) approach to examine factors like road geometry, pedestrian flow and walking satisfaction. Even though their study revealed a relationship between service levels and pedestrian satisfaction, it potentially lacks focus on how individual sidewalk characteristics impact overall user satisfaction. Said et.al (2017) applied Structural Equation Modelling (SEM) to explore ease of crossing, sidewalk blockage, cleanliness, vehicular traffic and motorcycles. They identified that there is a significant relationship between walking environment characteristics and overall satisfaction. Rani et al. (2018) developed a walkability model using nine significant independent variables through stepwise regression and factor analysis, considering socio-demographic characteristics, safety from traffic and crime, pedestrian convenience, sidewalk infrastructure and accessibility. However, while their approach effectively identifies significant variables and underlying structures, it may not capture the ordinal nature of user satisfaction levels, highlighting a gap in understanding how specific sidewalk characteristics affect overall pedestrian satisfaction.

Rahimi (2019) provided quantitative and qualitative pedestrian Level of Service (LOS) scores, focusing on pedestrian flow rate per unit width and average pedestrian space. The study concluded that aesthetics significantly affects the pedestrian experience. Bivina and Parida (2019) used SEM to study variables like safety, security, mobility, infrastructure and comfort. Their findings indicated that police patrolling, street lights, cleaner sidewalks, sidewalk impediments and surface conditions affect sidewalk (LOS). Sahani and Bhuyan (2020) employed Ridge Regression and GA-Fuzzy Clustering, focusing on gender, age, platoon size (PS), traffic score (TS), safety score (SS), comfort score (CS), maintenance score (MS) and aesthetic score (AS). They noted that only qualitative variables were considered and suggested a different modeling approach incorporating those variables. Isradi et al. (2021) applied Importance Performance Analysis (IPA) and LOS method based on HCM 2000. They considered the physical condition of sidewalks, pedestrian satisfaction levels and sidewalk service levels. Their findings emphasized the importance of physical infrastructure, amenities and environmental features, functional and user experience factors. Majumdar et.al (2021) applied the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) and Importance–Satisfaction Analysis (ISA). They considered 15 sidewalk and 11 crosswalk related attributes influencing safety and walkability. The study identified significant sidewalk qualities such as physical isolation from traffic, amenities, width, continuity and cleanliness. Lee et al. (2021) used binary and ordered logit models to study land use and separated versus non-separated sidewalks. Their research found that less illegal parking, increased pedestrian space, guidance and green space boost happiness and physical factors like separated sidewalks increase satisfaction.

Johanes et al. (2022) also utilized (IPA) to examine variables such as pedestrian volume, speed, characteristics and satisfaction. Their study highlighted that the availability of garbage bins, drainage channels, sidewalk slope (continuity), surface condition and affordability of accessible public transportation were critical factors. Rani et al. (2021) assessed walkability across Indian cities using clustering analysis, identifying patterns across various urban typologies. They applied factor analysis, stepwise regression, and survey data to develop walkability models and set walkability thresholds. Ujjwal and Bandyopadhyaya in 2023 used the Ordered Probit Model to examine pedestrian volume and speed, physical characteristics, and perceived satisfaction levels. They developed a Pedestrian – LOS (PLOS) model for sidewalks in mixed land-use areas of old cities. Rossetti et al. (2024) highlighted recurring factors in assessing active mobility networks and has extensively explored numerous factors in the built environment and active mobility infrastructures that influence mobility features and demands. Several such studies have explored pedestrian perceptions near transit stations. Carra and Ventura (2020) found that improving pedestrian infrastructure enhances accessibility and mobility around transport nodes. Similarly, Tira et al. (2020) highlighted that urban environments significantly impact pedestrian movement, particularly around station areas. However, these studies were conducted in developed countries, where urban settings differ from those in developing nations like India. This distinction underscores the need for contextual research in regions with unique pedestrian challenges, such as encroachments and vehicular conflicts.

These studies demonstrate the importance of emotional perceptions, physical components and service quality in sidewalk design and also significance of pedestrian satisfaction. They illustrated that emotional perceptions should be given more importance over physical ones as they affect user satisfaction more. Evidence from various studies highlights that user’s perceptions of physical and user characteristics of sidewalk significantly influence walkability. However, research on these factors remains limited, especially in developing countries where sidewalk conditions are often inadequately maintained. To address these gaps, this paper underscores the need to integrate subjective measures of pedestrian satisfaction with sidewalks, especially around transit stations in developing countries. While previous research has largely focused on physical characteristics such as sidewalk width, surface quality and connectivity, these studies overlook the key perceptions like comfort, safety, security and comfort. Recognizing these subjective factors is crucial, as they greatly impact walking behaviour and overall satisfaction; incorporating them can provide deeper insights into pedestrian needs and preferences.

Moreover, many existing studies focus on macro-level urban planning or walkability factors, such as city-wide networks or neighbourhood designs, but often overlook micro-level assessments around high-demand transit hubs like metro terminals in developing countries like India especially in rapidly growing cities like Hyderabad. Assessing sidewalk conditions based on user satisfaction around terminal stations is critical, as these stations serve as key nodes for first- and last-mile connectivity, where pedestrian satisfaction plays a pivotal role in encouraging public transport use. Thus, this study examines users' perception on physical and user characteristics of sidewalks outside metro terminal station and developed an OLR model to describe how these characteristics affects users' OLS with sidewalks.

3. Methodology

This section outlines the systematic approach adopted in this study, beginning with the selection of study area, followed by data collection through questionnaire survey on user perceptions. The collected variables were then categorized and OLR was applied for analysis. Additionally, this section details the modeling approach used in the OLR analysis. The details of the study area and the data collection is provided in the subsequent sections (section 4).

The data was collected by conducting a structured face to face user perception and rating survey. Individual perceptions and ratings from commuters who are utilizing sidewalks outside these metro terminal stations are used to estimate users' 'OLS'. In this regard, the commuters were asked to rate sidewalk's physical and user characteristics. This data was statistically analysed to examine their effect on 'OLS'. An OLR model was developed for this study, as it effectively handles ordinal data. This modeling technique is well-suited for analysing how ratings of sidewalk features influence the 'OLS' (Agresti, 2010; Long and Freese, 2014). The variables considered for this study are presented in Table 1. The variables identified as significant in previous studies were chosen to represent the physical and user characteristics of sidewalks, ensuring a comprehensive analysis of factors influencing pedestrian satisfaction.

In this analysis, we incorporated these variables hypothesized to impact pedestrian satisfaction, categorized into physical and user characteristics. Using these variables, we aimed to conduct a comprehensive evaluation of the key factors affecting pedestrian satisfaction around metro terminals. The physical characteristics include Surface Condition (SC), referring to the quality and maintenance of the sidewalk surface; Width (W), the available sidewalk width affecting comfort and ease of movement; Obstructions (Obs), the presence of physical obstacles like poles or debris; Potential for Vehicular Conflict (PVC), factors that increase the likelihood of pedestrians encountering vehicles; and Continuity (Con), the uninterrupted flow of the sidewalk network. The user characteristics consist of Encroachment (Enc), unauthorized use of sidewalk space by vendors or parked vehicles; Walk Environment (WE), the overall ambiance including aesthetics and cleanliness; Safety, Security and Comfort (SSC), the pedestrians' perception of these factors; and Overall Level of Satisfaction (OLS), the cumulative satisfaction of users with sidewalk conditions. A mathematical model was developed, considering 'OLS' as dependent variable and others as independent. The details of the modelling approach were demonstrated in the subsequent sections (section 3.1)

3.1 Modeling approach

This section demonstrates the OLR modeling approach to quantify the association between sidewalk characteristics and users' 'OLS', according to the methodology illustrated in Figure 1.

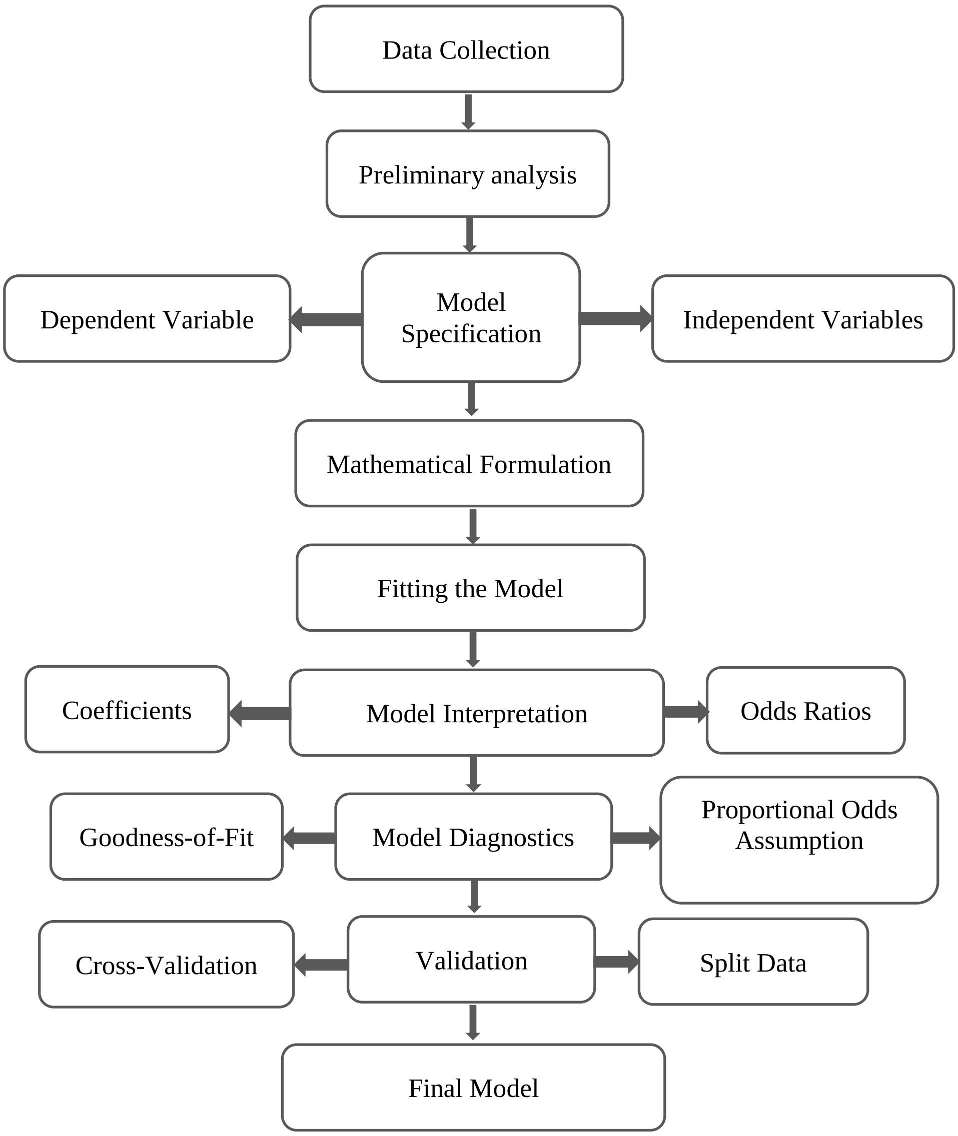

Figure 1: Detailed methodology for developing OLR model

This model estimates satisfaction probabilities based on various predictor factors. The conceptual framework posited that the physical and user attributes of sidewalks affect the 'OLS' (see Table 1). Data on these attributes were collected from commuters at metro terminal stations through a user perception and rating survey employing a five-point Likert scale which was explained in detail in the subsequent parts of this paper in section

4. These respondents' ratings on sidewalk features generated an ordinal dataset to obtain the model.

Table 1: Physical and user characteristics of sidewalk chosen for study

Sl.No	*Physical characteristics*	*Abbreviation*	*Sl.No*	*User characteristics*	*Abbreviation*
1	Surface condition	SC	6	Encroachment	Enc
2	Width	W	7	Walk Environment	WE
3	Obstructions	Obs	8	Safety, Security and Comfort	SSC
4	Potential For Vehicular Conflict	PVC	9	Overall Level of Satisfaction	OLS
5	Continuity	Con			

In this study, 'OLS' is the predicted variable, whereas, other variables are predictor variables. The general form of the OLR model is presented below in Eq. 1.

$$\text{logit}(P(Y \leq j) = \alpha_j - (\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_K X_K) \quad (1)$$

where Y is the ordinal outcome 'OLS', j represents the thresholds for the ordinal levels (1-5), α_j are the cut points (threshold parameters), β_k are the regression coefficients for the predictor variables X_k and k represents total number of predictor variables.

Data analysis and model development were performed using R statistical software. In this, the model coefficients were estimated using the Maximum Likelihood Estimation (MLE) method to optimize the likelihood function based on the observed data. To ensure the validity of the model, the proportional odds assumption was evaluated. Goodness-of-fit statistics, including the likelihood ratio test, Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC), were employed to assess the model fit. The odds ratios provided clear interpretations of how each predictor influenced the outcome categories. Positive odds ratios indicate a positive association, whereas negative odds ratios imply a negative relationship. These ratios were calculated by exponentiating each predictor's coefficient, as shown in Eq. 2.

$$\text{Odds Ratio} = e^{\beta k} \quad (2)$$

To interpret the results, the estimated coefficients (β) was employed to determine the direction and magnitude of each predictor's impact on the 'OLS'. Positive coefficients indicate that the predictor variable positively influences user satisfaction, increasing the likelihood of higher satisfaction ratings. Conversely, negative coefficients denote that the predictor variable negatively affects user satisfaction, decreasing the likelihood of higher satisfaction ratings. This modeling technique was adopted to analyse the parameters affecting user satisfaction with urban sidewalks near metro terminal stations, enabling us to identify the key factors and their significance contribution on pedestrian satisfaction with sidewalk in study area. Furthermore, to gain a deeper understanding of how each predictor variable influences the 'OLS', individual category probabilities are calculated for each satisfaction level ranging from "Very Dissatisfied" to "Very Satisfied"—using Eq. 3 which is a cumulative logistic function. This calculation allows us to estimate the likelihood that a pedestrian falls into a specific satisfaction category based on their ratings of the sidewalk characteristics.

$$P(Y = j) = P(Y \leq j) - P(Y \leq j - 1) \quad (3)$$

Where:

$P\ (Y=j)$ is the probability of a respondent being exactly in satisfaction category j.

$$P\ (Y \leq j) = \frac{1}{1 + e^{-(\alpha_j - \beta_1 X_1 - \beta_2 X_2 - \beta_3 X_3 - \beta_4 X_4 \ldots\ldots\ldots\ldots \beta_k X_k)}}$$

$P\ (Y \leq j)$ is the cumulative probability (calculated using logistic function) of a respondent being in category j or any lower category; $P\ (Y \leq j\text{-}1)$ is the cumulative probability up to the category just below j. α_j is the threshold parameter (also known as the cut point or intercept) for satisfaction category j. β_k are the estimated coefficients for each predictor variable X_k. X_k represents the value of the k^{th} predictor variable for a respondent. k is the total number of predictor variables.

4. Selection of study area and data collection

This study focuses on the Hyderabad Metro Rail (HMR), a 69 km network across three corridors, with terminal stations at LB Nagar-Miyapur (Corridor I) and Nagole-Raidurg (Corridor II), seamlessly connecting key commercial, residential and IT hubs. Serving nearly 5 lakh passengers each day, the metro's Red and Blue Lines experience the highest footfall, underscoring the city's increasing need for efficient public transit. These terminal stations were chosen based on their ridership volumes, strategic location at terminal points and their role in first- and last-mile connectivity. Each terminal handles around 29,000 to 32,000 passengers per day, serving as vital nodes for transit operations and promoting public transport through bus service interchanges. Nagole-Uppal stations were studied together due to their proximity and similar travel patterns. The geographic location of these stations is shown in Figure 2.

Moreover, despite efforts to improve walkability, walking infrastructure around these stations remains a significant challenge. With heavy pedestrian activity, ensuring seamless first- and last-mile connectivity is crucial. Congestion during peak hours and poorly planned pedestrian pathways continue to hinder the overall commuter experience. Addressing these issues will encourage additional commuters to walk to transit stations, enhancing overall accessibility and convenience thereby user satisfaction.

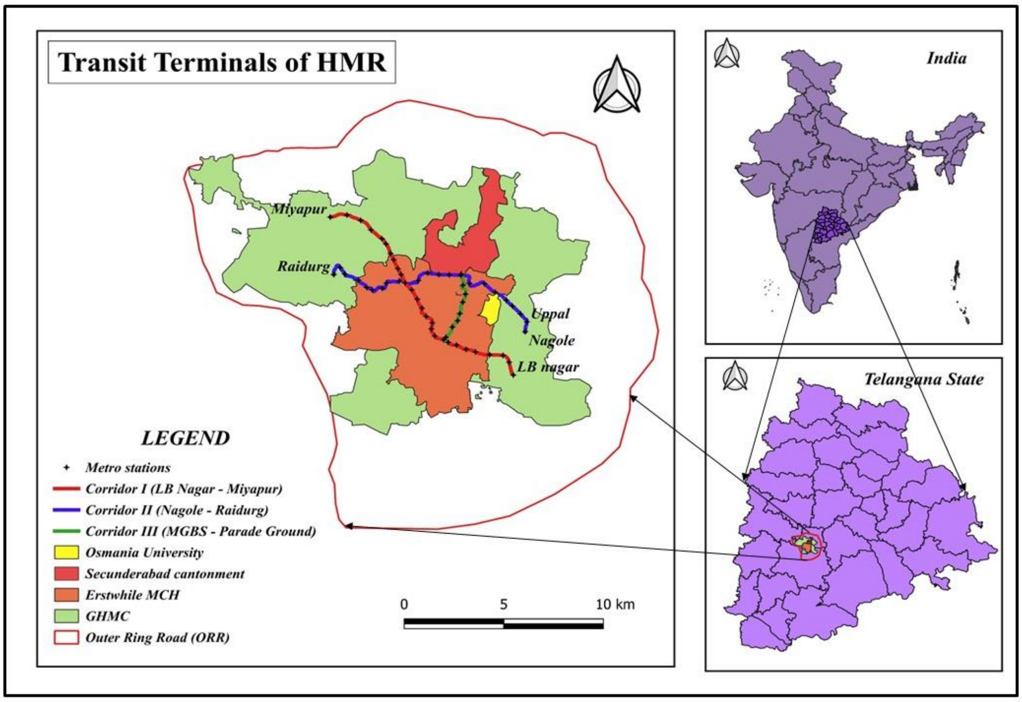

Figure 2 : Location of Metro Terminals

In order to examine the current satisfactions level of commuters, user perception data was collected from all four stations and clubbed together to develop a model whose dependent variable will be 'OLS' which is ordered type with multiple levels. Sample size was estimated for each station based on the stations' average footfall per day, to obtain accurate results.

Accordingly, the number of samples for each station was determined using G*Power software, with the parameters set to a 95% confidence level, 80% statistical power, 5% margin of error and an assumed medium effect size (0.5); the resulting sample size recommendations ranged between 200 and 400 participants, depending on the specific analysis type and station-wise footfall variability. Table 2 depicts the number of user perception samples collected at each station.

Table 2: Survey samples collected for each transit station

Name of the Metro Station	*Number of survey samples collected*
Miyapur (Red Line)	299
LB Nagar (Red Line)	310
Nagole and Uppal (Blue Line)	246
Raidurg (Blue Line)	381
Total number of samples	1236

4.1 Data collection

Subsequently, primary data was collected using a well-structured questionnaire. This comprises information on demographic characteristics (age, gender, occupation, distance from transit station to destination), travel characteristics (frequency of using the transit per week, purpose of travel, mode of access to the metro terminal, preferred mode of travel), user perception and ratings. Variables considered for collecting user satisfaction, was rated on a Five-point Likert scale as shown in Table 3.

In this study, the survey was conducted between 7:00 AM to 8:00 PM over a period of four-month, from August to December 2023, focusing on gathering insights into pedestrian behaviour and preferences related to sidewalk use. A strategic sampling approach was employed, wherein every three out of five individuals encountered were selected as respondents. This method ensured diversity and randomness in the data, minimizing selection bias. Face-to-face interviews were conducted and a total of 1,300 samples were collected during the survey period. After thorough data cleaning and validation, 1,236 samples were considered for the analysis, accounting for approximately 95% of the total responses as shown in Table 2.

Table 3: User rating options for sidewalk characteristics

Characteristics of sidewalks	*Options*
SC	Very Good, Good, Neutral, Poor, Very Poor
W	Very Good, Good, Neutral, Poor, Very Poor
Obs	Very Less, Less, Moderate, High, Very High
PVC	Very Less, Less, Moderate, High, Very High
Enc	Very Less, Less, Moderate, High, Very High
SSC	Very Good, Good, Neutral, Poor, Very Poor
Con	Very Good, Good, Neutral, Poor, Very Poor
WE	Very Good, Good, Neutral, Poor, Very Poor
OLS	Very Satisfied, Satisfied, Neutral, Dissatisfied, Very Dissatisfied

(SC, W, SSC, Con, WE): Very Good – 1, Good – 2, Neutral – 3, Poor – 4, Very Poor – 5; (Obs, PVC, Enc): Very Less – 5, Less – 4, Moderate – 3, High – 2, Very High – 1); (OLS): Very Satisfied – 5, Satisfied – 4, Neutral – 3, Dissatisfied – 2, Very Dissatisfied – 1

5. Preliminary Analysis

Analysis of the demographic and travel characteristic data collected during field surveys shows that metro users at LB Nagar, Miyapur, Nagole-Uppal and Raidurg stations are predominantly male (see Figure 3). The data evaluation indicates that the majority of users are of working age, specifically in the 26–35 age group, with Miyapur station having 38% of users in this category (see Figure 4). The data reveals that working professionals constitute 40% of metro users at LB Nagar and Raidurg stations (see Figure 5). The majority of trips are within a 1–2 km radius of the metro stations (see Figure 6). Work is the primary purpose for commuters making 2–5 weekly trips, particularly prominent at Raidurg (see Figure 7 & 8). Figure 8 illustrates that work-related trips are highest in Raidurg (50%) and lowest in Nagole-Uppal (34%); education trips peak in Miyapur (23%) and are lowest in LB Nagar (12%); leisure trips are most common in Nagole-Uppal (28%) and least common in Raidurg (16%), with trips for other purposes generally lower across all stations.

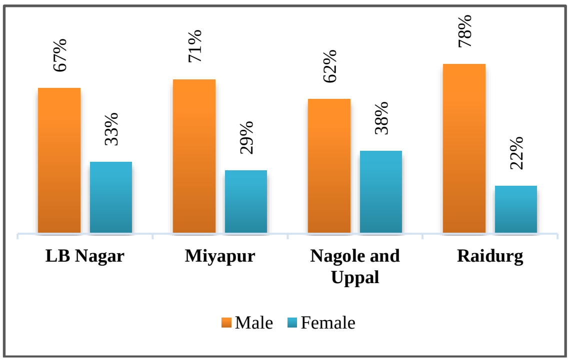

Figure 3:Gender Distribution

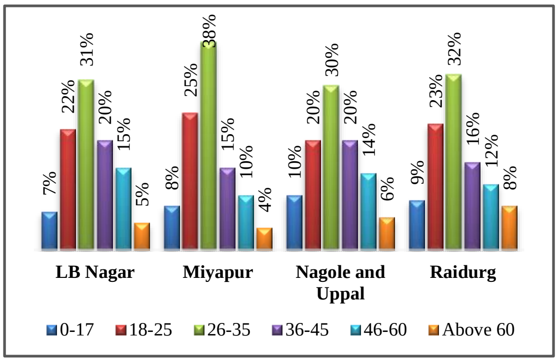

Figure 4:Age Distribution

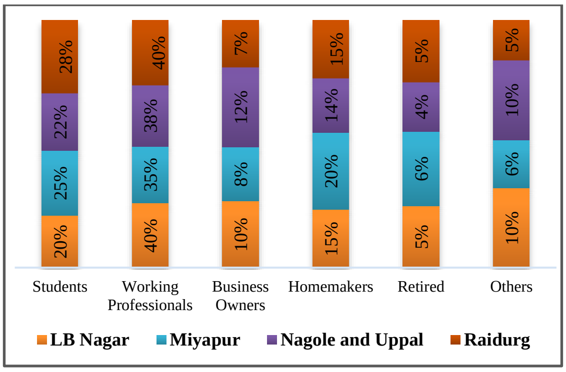

Figure 5: Occupation of metro users

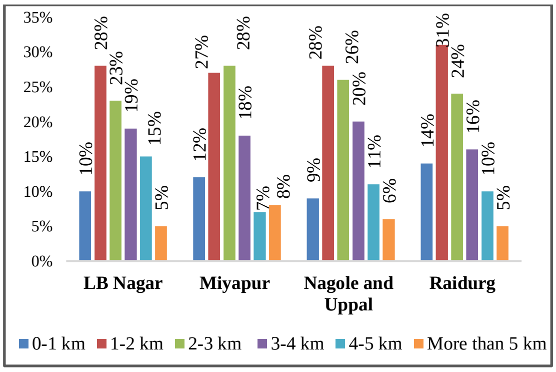

Figure 6: Distance from metro station

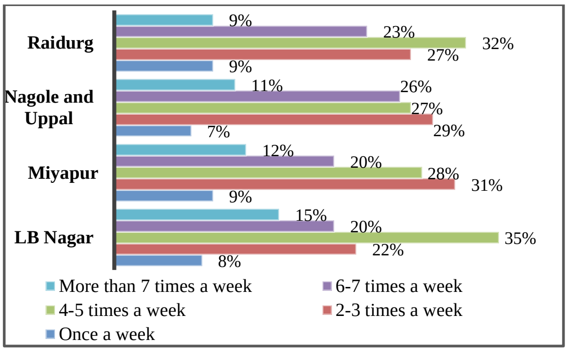

Figure 7: Frequency of metro use

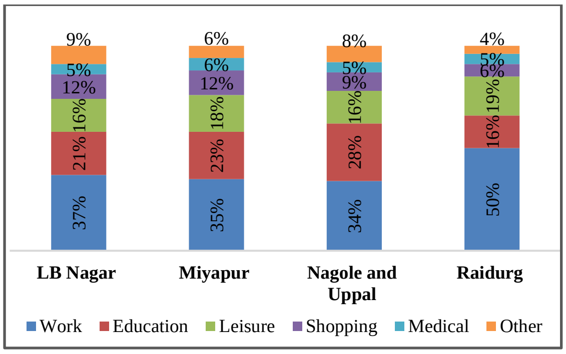

Figure 8: Trip purpose

Figure 9 depicts that commuters from Nagole-Uppal are using two-wheelers (31%) and ride-hailing services (8%), while those from Raidurg are utilising cars (24%) and foot (24%). Commuters from Miyapur rely more on auto-rickshaws (21%) and buses (18%), indicating varied transport needs across different areas influenced by urban design and socio-economic factors. As evident from Figure 10, walking is the most preferred mode for accessing metro terminals, with 35% of passengers in Raidurg and 30% in Miyapur choosing to walk.

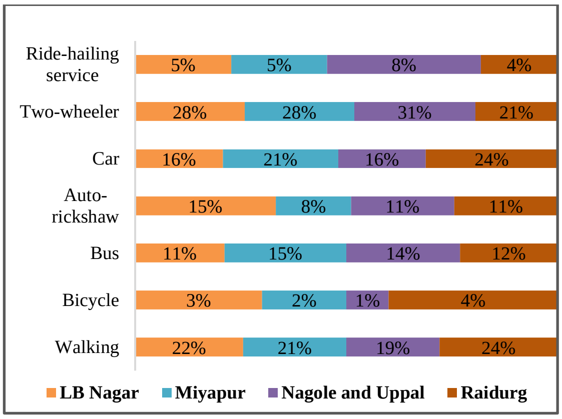

Figure 9: Access or Egress trip mode

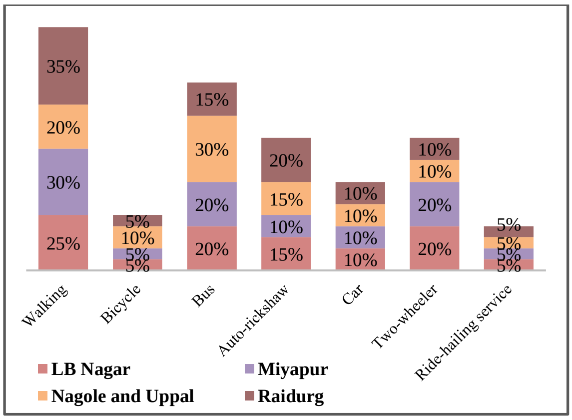

Figure 10: Preferred mode for trip

Analysis of user satisfaction ratings of sidewalk characteristics at the four metro terminals is presented in the subsequent figures. These are crucial for promoting walkability, enhancing pedestrian safety and improving the attractiveness and usability of sidewalks around metro terminals. Higher ratings of these variables indicate increased user satisfaction.

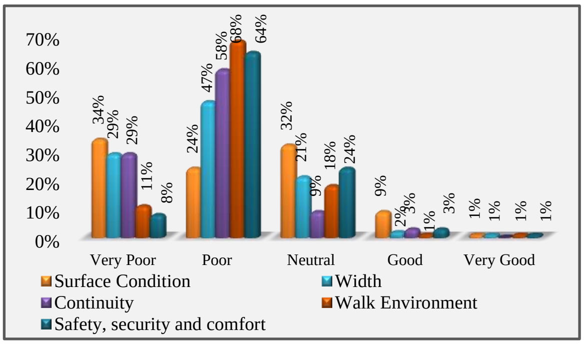

Figure 11: User rating for Miyapur (a)

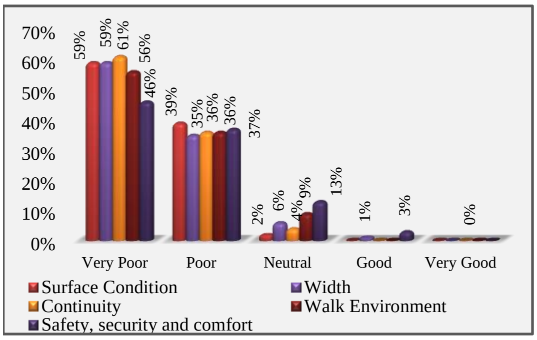

Figure 12: User rating for Nagole-Uppal (a)

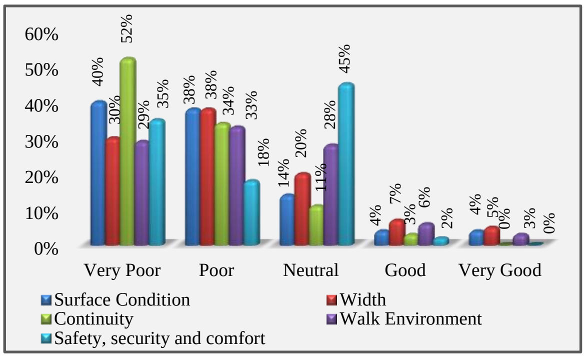

Figure 13 : User rating for LB Nagar (a)

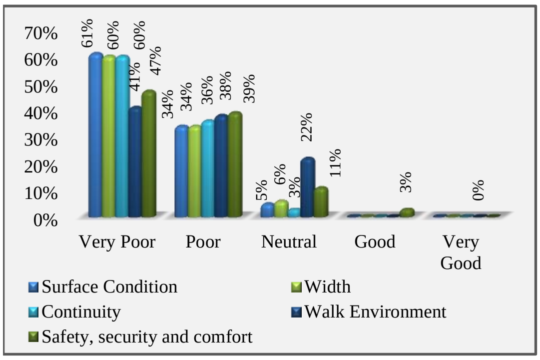

Figure 14 : User rating for Raidurg (a)

The data from the above charts reveal a significant level of user dissatisfaction with various sidewalk characteristics across the metro terminals. At Miyapur, 'WE' received the highest poor rating, with 68% of users expressing dissatisfaction. This was closely followed by 'SSC' at 64% and 'Con' at 58% (see Figure 11). Where as in Nagole-Uppal, very poor ratings dominated, with 'SC', 'W' and 'Con' each receiving approximately 59–61% very poor ratings. Similarly, high levels of dissatisfaction were observed for 'WE' and 'SSC' at these terminals (see Figure 12). LB Nagar, while showing slightly better results, still reflected concerning levels of dissatisfaction, particularly in 'Con' with 52% very poor ratings and 'SC' with 40% very poor ratings. Poor ratings were significant for 'W' at 38% and 'WE' at 33% (see Figure 13). Feedback from Raidurg mirrored that of Nagole-Uppal, with very poor ratings in 'SC', 'W' and 'SSC' all at 60–61% (see Figure 14). The overall analysis indicates that neutral and positive ratings were minimal across all terminals, emphasizing a critical need for improvements. The high levels of very poor and poor ratings across 'Con', 'WE' and 'SSC' indicate substantial issues that require immediate attention to enhance user satisfaction and experience at these stations.

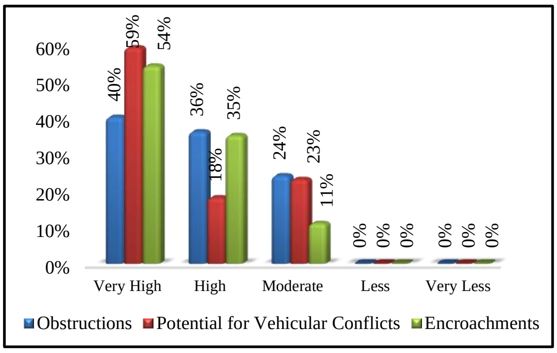

Figure 15: User rating for LB Nagar (b)

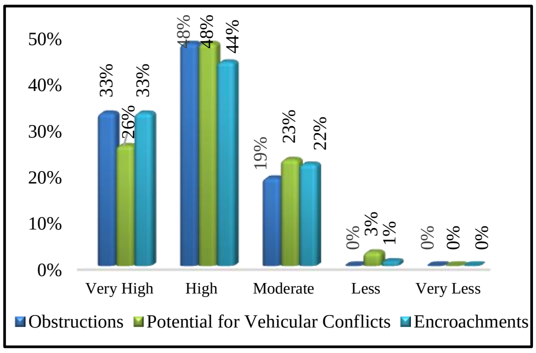

Figure 16: User rating for Raidurg (b)

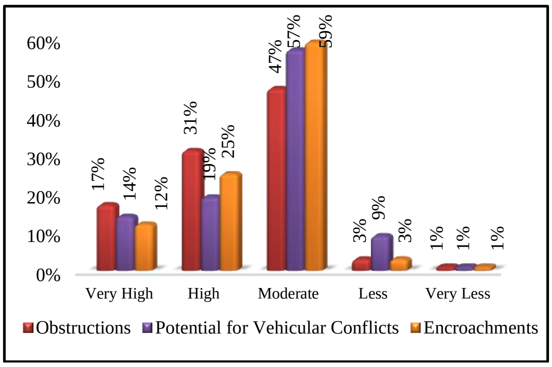

Figure 17: User rating for Miyapur (b)

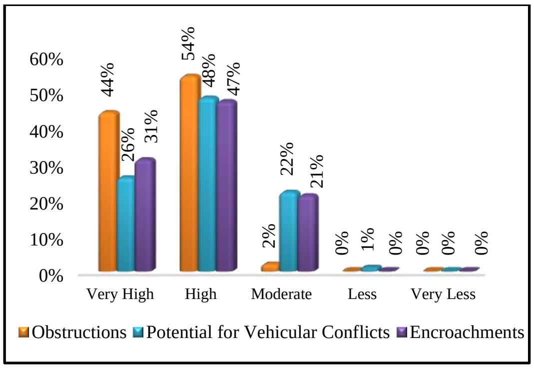

Figure 18: User rating for Nagole-Uppal (b)

The user satisfaction data on 'Obs', 'PVC' and 'Enc' at four terminals revealed significant concerns across all locations. At LB Nagar (see Figure 15), 40% of users reported very high levels of 'Obs', indicating frequent barriers on sidewalks. Similarly, users perceived a very high 'PVC', underscoring safety concerns, while 54% cited very high levels of 'Enc'. Raidurg (see Figure 16) exhibited similar issues, with 'PVC' and 'Enc' also being significant concerns. Miyapur showed significant dissatisfaction, with 34% of users reporting very high 'Obs' and 47% noting high 'PVC' (see Figure 17). 'Enc' were also a major issue, with 29% of users rated them as very high. At Nagole - Uppal, the situation was particularly severe, with very high 'Obs' and very high 'PVC' (see Figure 18). 'Enc' were also rated very high by users for all stations. The data indicated widespread dissatisfaction at these terminals, particularly regarding 'Obs', 'PVC' and 'Enc'.

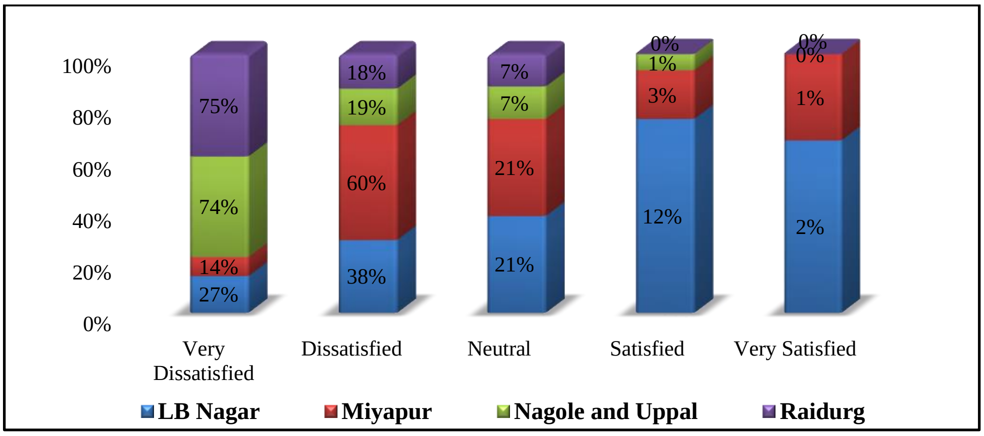

Figure 19: User rating on overall satisfaction with sidewalks outside terminal stations

The 'OLS' data indicates significant dissatisfaction with sidewalk conditions at four metro terminals. At LB Nagar, the majority of users expressed dissatisfaction. Miyapur fared similarly, with an even higher proportion of dissatisfied users. Nagole-Uppal exhibited the highest levels of dissatisfaction, with virtually no users reporting satisfaction—a trend mirrored at Raidurg. The predominant issues likely include poor 'SC', inadequate 'W', frequent 'Obs', high incidence of 'PVC', 'Enc' and lack of ‘SSC' (see Figure 19).

6. Detailed Analysis and Results

The crucial aspect of this paper is to model the users’ OLS with sidewalks at metro terminals. Given the nature of satisfaction, which was typically measured on an ordinal scale (Very dissatisfied to Very satisfied), OLR suits well for this analysis. The primary purpose of using OLR in this study is to, systematically evaluate the factors influencing the OLS with sidewalks, which was inherently ordinal in nature. By incorporating multiple independent variables the model enabled a comprehensive analysis of the key factors affecting pedestrian satisfaction.

6.1 Model Specification

The general form of the OLR model, integrating the various independent variables, is represented in Eq. 4:

$$P\ (Y \le j) = \alpha_j - (\beta_1 * SC + \beta_2 * W + \beta_3 * Obs + \beta_4 * PVC + \beta_5 * Enc + \beta_6 * Con + \beta_7 * WE + \beta_8 * SSC) \quad (4)$$

Each coefficient represents the change in the log-odds of the dependent variable being in a lower category per unit increase in the corresponding independent variable. A positive coefficient (β_i >0) indicates that an increase in the independent variable increases the likelihood of the dependent variable being in a higher satisfaction category. Conversely, a negative coefficient (β_i <0) indicates that an increase in the independent variable decreases the likelihood of the dependent variable being in a higher satisfaction category.

6.2 Statistical Analysis

Figure 20 represents descriptive statistics for various variables, each measured on a Five point Likart scale with maximum value as 5 and minimum value as 1. The mean and standard deviation values of 'SC' indicates poor sidewalks surface, while the widths' are narrow. 'Obs' values shows significant obstructions on the sidewalks and 'PVC' values indicates moderate to high chances for conflicts. It is evident that there are illegal occupation of pedestrian paths with poor continuity of the path. Additionally, pedestrian environment and perceptions on comfort are poor there by reflecting that 'OLS' is low, indicating dissatisfaction.

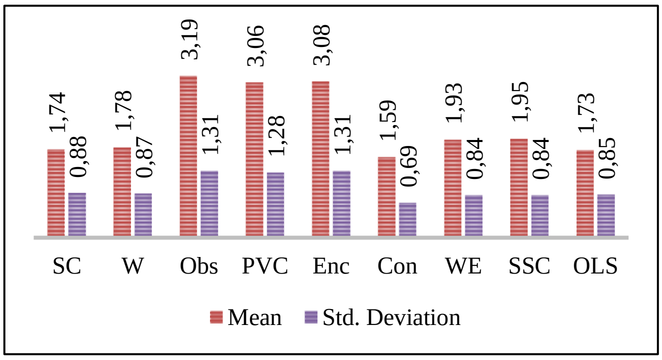

Figure 20: Descriptive statistics of various Variables

Where as, Figure 21 displays model fit matrix across iterations, with best-fit model selected based on minimized deviance and McFadden R² values. This model's fit measures, listed in Table 4, show the deviance as 2354, with AIC and BIC values of 2426 and 2610, respectively, and an R² of 0.235, indicating a robust fit.

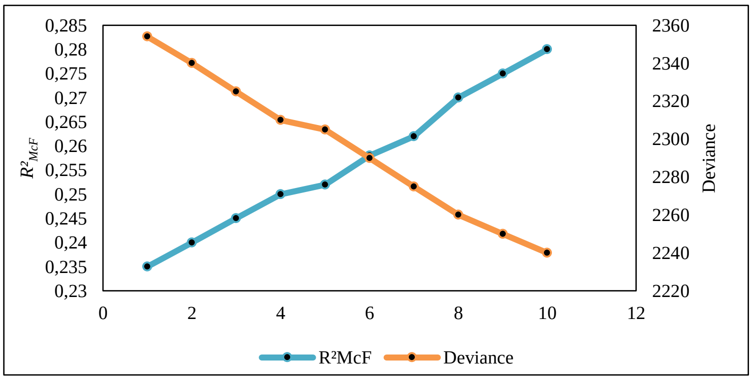

Figure 11: Goodness - of - fit: Deviance and R^2McF over Model Iterations

Table 4: Model fit measures

Model	*Deviance*	*AIC*	*BIC*	*R^2_{McF}*	*Overall Model Test*

					χ^2	df	p
1	2354	2426	2610	0.235	724	32	< .001*

* p< 0.05; **p< 0.01

6.3 Omnibus Likelihood Ratio Test and Model Coefficients

The omnibus test results, illustrated in Figure 22, highlight significant impacts of factors on user satisfaction with sidewalks around metro terminals. 'SC', 'W', 'Obs' and 'SSC' had highly significant impacts, with chi-square values of 11.66, 32.02, 17.50 and 40.60 respectively and p-values all less than 0.001. 'PVC', 'Con', 'Enc' and 'WE' also showed significant effects, with respective p-values as 0.003, 0.03, 0.006 and 0.040.

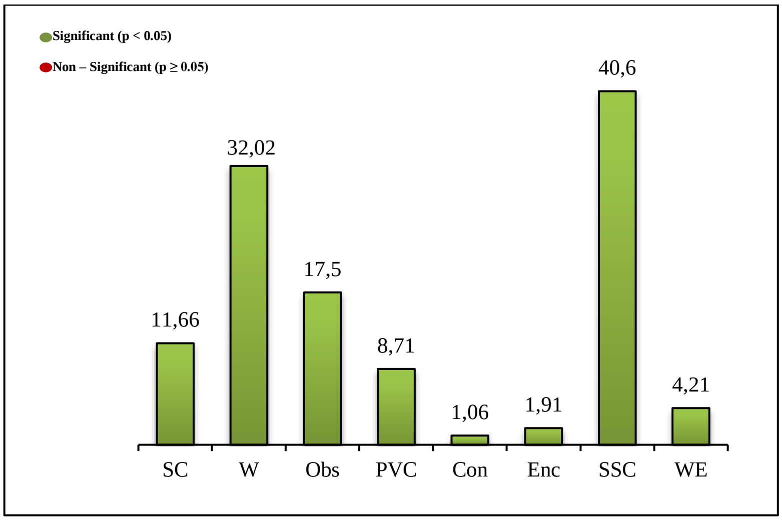

Figure 22: Results of Omnibus Likelihood Ratio Test

Table 5: Model coefficients - OLS

		95% Confidence Interval						*95% Confidence Interval*	
Variable	*Estimate*	*Lower*	*Upper*	*SE*	*Z*	*p*	*Odds ratio*	*Lower*	*Upper*
SC	0.23	0.09680	0.3546	0.0657	3.43	< .001	1.253	1.102	1.426
W	0.39	0.25571	0.5279	0.0694	5.64	< .001	1.479	1.291	1.695
Obs	-0.28	-0.41553	-0.150	0.0678	-4.16	< .001	0.754	0.660	0.861
PVC	-0.21	-0.34373	-0.069	0.0700	-2.95	0.003	0.813	0.709	0.933
Con	0.09	0.25430	0.0790	0.0850	1.03	0.03	0.917	0.775	1.082
Enc	-0.10	-0.24662	-0.043	0.0738	-1.38	0.01	0.903	0.781	1.044
SSC	0.45	0.31426	0.5947	0.0715	6.35	< .001	1.575	1.369	1.813
WE	0.15	0.00655	0.2938	0.0732	2.05	0.040	1.162	1.007	1.341

* p< 0.05; **p< 0.01

The results from Table 5 revealed significant findings regarding user satisfaction with sidewalk conditions outside metro terminals. 'SC', 'W', 'SSC' and 'WE' had positive effects on user satisfaction, with coefficients indicating increased likelihood of higher satisfaction categories. Specifically, 'SC' had an odds ratio of 1.253, 'W' had an odds ratio of 1.479, 'SSC' had an odds ratio of 1.575 and 'WE' had an odds ratio of 1.162, all with p-values less than 0.05, indicating strong statistical significance.

Conversely, 'Obs' and 'PVC' had negative effects on satisfaction, with odds ratios of 0.754 and 0.813, respectively, both with p-values less than 0.01, indicating significant negative impacts. 'Enc' also showed a negative effect, with an odds ratio of 0.903, but its significance was less pronounced with a p-value of 0.01. 'Con' had a positive effect, with an odds ratio of 0.917 and a p-value of 0.03, indicating a modest positive impact. The findings of the model demonstrated that improving 'SC', 'W', 'SSC' and 'WE' could enhance user satisfaction, while reducing 'Obs' and 'PVC' could mitigate dissatisfaction. Immediate attention to these factors is essential for improving the pedestrian experience outside metro terminals. The general form of developed OLS model is illustrated in Eq. 5.

$$P(Y \leq j) = \alpha_j - (0.23*SC+0.39*W-0.28*Obs-0.21*PVC-0.10*Enc+0.09*Con+0.15*WE+0.45*SSC) \quad (5)$$

Table 6: Model Thresholds

Threshold	*Estimate*	*SE*	*Z*	*p*	*Odds ratio*
1 | 2	1.68	0.387	4.34	< .001	5.36
2 | 3	3.96	0.408	9.69	< .001	52.33
3 | 4	6.33	0.506	12.53	< .001	563.73
4 | 5	8.06	0.817	9.88	< .001	3176.92

* p< 0.05; **p< 0.01

The OLR model revealed significant thresholds between user satisfaction levels with sidewalks outside metro terminals (see Table 6). The transition from very dissatisfied to dissatisfied rating required a notable positive shift (estimate 1.68, odds ratio 5.36). Moving from dissatisfied to neutral rating needed an even larger shift (estimate 3.96, odds ratio 52.33), and from neutral to satisfied required substantial improvement (estimate 6.33, odds ratio 563.73). The highest threshold was for moving from satisfied to very satisfied, needing the most considerable positive change (estimate 8.06, odds ratio 176.92). All thresholds were highly significant ($p < 0.001$), indicating robust distinctions between satisfaction levels and emphasizing the need for substantial improvements to enhance user satisfaction.

6.4 Predicted Probabilities for Satisfaction Levels

The predicted probabilities for each satisfaction level, illustrates how likely respondents are to fall in each category from "Very Dissatisfied" to "Very Satisfied." The corresponding equations for each category of OLS are as shown in Eq. (6). The obtained probabilities are shown in Figure 23.

$$\left.\begin{aligned} &P(Y=1) = P(Y \leq 1) \\ &P(Y=2) = P(Y \leq 2 \mid X) - P(Y \leq 1) \\ &P(Y=3) = P(Y \leq 3 \mid X) - P(Y \leq 2) \\ &P(Y=4) = P(Y \leq 4 \mid X) - P(Y \leq 3) \\ &P(Y=5) = 1 - P(Y \leq 4) \end{aligned}\right\} \quad (6)$$

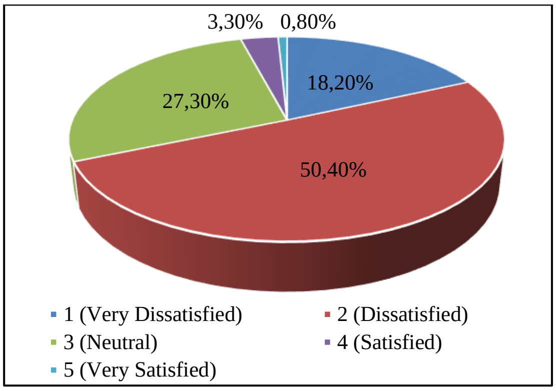

Figure 23: Results of Probability Predictions

6.5 Model Validation

To validate the OLR model's predictive accuracy, 25% of the dataset was used for independent testing, assessing how well the model predicts satisfaction levels. Achieving an accuracy rate of 64.40% calculated as the ratio of correct predictions (see Table 7) to total responses, shown in Eq. 7 may seem moderate; however, this rate reasonably reflects the challenges of capturing the variability in traveler perceptions and subjective ratings. The results revealed some alignment issues between user perceptions and their representation in standard manuals and codes, indicating that current guidelines may lack sensitivity to the nuanced experience of travelers. These insights underscore areas for improvement in transportation planning resources. Overall, the validation confirms that, despite challenges, the model provides a meaningful representation of user satisfaction, making it a valuable yet adaptable tool for transportation planning.

$$Accuracy\ of\ model\ prediction = \frac{Total\ number\ of\ correct\ predictions}{Total\ number\ of\ responses} \qquad (7)$$

Table 7: Confusion matrix

	Very Dissatisfied	*Dissatisfied*	*Neutral*	*Satisfied*	*Very Satisfied*
Very Dissatisfied	120	46	30	25	23
Dissatisfied	41	180	27	40	29
Neutral	24	23	110	24	20
Satisfied	29	20	29	160	23
Very Satisfied	18	24	23	18	130

7. Discussion and Conclusions

Sidewalks play a vital role in urban mobility, and their quality directly impacts commuter satisfaction. Hence, modeling the OLS with sidewalks outside metro terminals using a user-centric approach is crucial for understanding and improving pedestrian experience. A comprehensive analysis was conducted to explore metro users' perceptions of sidewalks around terminal stations of HMR through a user perception survey. The survey captured both physical and user characteristics of sidewalks and was modeled using OLR, with 'OLS' as the dependent variable. The developed OLR model effectively identified key variables such as 'SC', 'W', 'Obs', 'PVC', 'Enc', 'Con', 'WE' and 'SSC' that significantly impacted user satisfaction.

The model's McFadden pseudo-R-square (ρ^2) value of 0.235, within the acceptable range (0.2–0.4), indicates a good fit, with safety, security and comfort emerging as key factors influencing commuter satisfaction, followed by sidewalk width and surface condition, while continuity and walk environment were less significant. Obstructions and potential vehicular conflicts had stronger negative impacts than encroachments, as indicated by negative coefficients and odds ratios below 1 (Obs: 0.754, PVC: 0.813), while 'SC', 'W', 'SSC', and 'WE' positively affected satisfaction with high odds ratios (SC: 1.253, W: 1.479, SSC: 1.575, WE: 1.162). For instance, 'SC' had a coefficient of 0.23 and a p-value < 0.001, showing that better sidewalk conditions significantly increase satisfaction, though encroachments ('Enc') had a smaller negative effect (odds ratio: 0.903). Significant thresholds for transitioning between satisfaction levels revealed the increasing difficulty of achieving higher satisfaction, with shifts from very dissatisfied to dissatisfied (threshold: 1.68, odds ratio: 5.36) and from dissatisfied to neutral (threshold: 3.96, odds ratio: 52.33) requiring moderate improvements, while moving to satisfied (threshold: 6.33, odds ratio: 563.73) and very satisfied (threshold: 8.06, odds ratio: 3176.92) demanded substantial enhancements.

Therefore, we can accomplish that the study revealed considerable dissatisfaction, especially with safety, obstructions, vehicular conflicts and encroachments, underscoring areas for improvement. Although the model achieved a moderate prediction success rate of about 65%, it effectively reflected user perceptions and emphasized discrepancies between actual user experiences and existing standards. Model predictions indicated that only 4% of respondents were satisfied with the current sidewalks, while 96% were less or not satisfied. The significant thresholds in the model suggest that even small shifts in satisfaction levels could lead to notable improvements in user perceptions.

This methodology is adaptable to other urban contexts, allowing cities to modify variables based on their local conditions. For instance, challenges like encroachments and vehicular conflicts are particularly relevant in Indian cities like Hyderabad but may not apply in other settings in developed nations. Data collection methods, including survey timing, sample sizes and station selection, must also align with local travel patterns. Despite the contextual nuances, the use of OLR offers a robust, flexible framework for understanding pedestrian perceptions across cities.

The proposed framework offers urban planners a scalable tool to assess sidewalk infrastructure and identify key factors influencing OLS, especially around transit hubs. This empowers evidence-based interventions to enhance first- and last-mile connectivity and foster sustainable urban environments. While this study provides valuable insights into pedestrian satisfaction, the study's geographic scope and the subjective nature of the data present certain limitations. With data collected from only four metro stations in Hyderabad, the results may not fully capture the broader pedestrian experience across the entire metro network or other urban areas, despite efforts to select diverse locations. The reliance on commuter surveys introduces subjectivity, as individual perceptions, biases and varying thresholds for satisfaction can influence responses, complicating efforts to derive universally applicable conclusions. Additionally, temporal factors, such as weather changes, traffic and time of day, as well as incorporating demographic segmentation, may affect survey outcomes, potentially impacting the consistency and reliability of the findings over time. Future research could extend to a corridor-level analysis, incorporating multiple stations, including MMTS (Multi – Modal Transit Systems) and bus stops, to gain a more comprehensive understanding of pedestrian experiences across the entire transit network.

References:

Agresti, A. (2010) Analysis of ordinal categorical data (Vol. 656). John Wiley & Sons.

Bhaduri, E., BS, M., Sen, J., Maitra, B. and Goswami, A.K. (2019) "Measuring user satisfaction of pedestrian facilities and its heterogeneity in urban India–A tale of three cities" Journal of the Eastern Asia Society for Transportation Studies, 13, pp.144-171. https://doi.org/10.11175/easts.13.144

Bivina, G.R. and Parida, M. (2019) "Modelling perceived pedestrian level of service of sidewalks: A structural equation approach" Transport, 34(3), pp.339-350. https://doi.org/10.3846/transport.2019.9819

Bivina, G.R., Gupta, A. and Parida, M. (2019) "Influence of microscale environmental factors on perceived walk accessibility to metro stations" Transportation Research Part D: Transport and Environment, 67, pp.142-155. https://doi.org/10.1016/j.trd.2018.11.007

Carra, M., & Ventura, P. (2020) "HSR stations' urban redevelopments as an impulse for pedestrian mobility. An evaluation model for a comparative perspective" In *Pedestrians, Urban Spaces and Health* (pp. 120-124). CRC Press.

Dandan, T.A.N., Wei, W.A.N.G., Jian, L.U. and Yang, B.I.A.N., (2007) "Research on methods of assessing pedestrian level of service for sidewalk" Journal of Transportation Systems Engineering and Information Technology, 7(5), pp.74-79. https://doi.org/10.1016/S1570-6672(07)60041-5

Deal Jr, E.C., McFadden Jr, E.R., Ingram Jr, R.H., Strauss, R.H. and Jaeger, J.J., 1979. Role of respiratory heat exchange in production of exercise-induced asthma. Journal of Applied Physiology, 46(3), pp.467-475. https://doi.org/10.1152/jappl.1979.46.3.467

Hussain, M.S., Kumari, R., Nimesh, V. and Goswami, A.K., (2021) "Assessing impact of urban street infrastructure on pedestrian safety perception" Proceedings of the Institution of Civil Engineers-Urban Design and Planning, 174(2), pp.76-84. https://doi.org/10.1680/jurdp.20.00033

Isradi, M., Fauziah, D.A.A., Dermawan, W.B., Mufhidin, A. and Prasetijo, J., (2021) "Analysis of Sidewalk User Satisfaction in Alun-Alun Bekasi" *ADRI International Journal of Engineering and Natural Science*, *6*(01), pp.1-11. http://adri.journal.or.id/index.php/ijens

Karatas, P. and Tuydes-Yaman, H., (2018) "Variability in sidewalk pedestrian level of service measures and rating" Journal of Urban Planning and Development, 144(4), p.04018042. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000483

Kwon, W., Kim, S., Choi, J., Kim, T., Jang, Y. and Kim, J., (2016) "A Study on Level of Service of Sidewalk and Satisfaction of Pedestrian" The Journal of The Korea Institute of Intelligent Transport Systems, 15(3), pp.129-145. http://adri.journal.or.id/index.php/ijens/index

Lee, S., Han, M., Rhee, K. and Bae, B., (2021) "Identification of factors affecting pedestrian satisfaction toward land use and street type" Sustainability, 13(19), p.10725. https://doi.org/10.3390/su131910725

Long, J.S., 2014. Regression models for nominal and ordinal outcomes. The SAGE handbook of regression analysis and causal inference.

Majumdar, B.B., Sahu, P.K., Patil, M. and Vendotti, N., (2021) "Pedestrian satisfaction-based methodology for prioritization of critical sidewalk and crosswalk attributes influencing walkability" Journal of Urban Planning and Development, 147(3), p.04021032. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000718

Mōri, M. and Tsukaguchi, H., (1987) "A new method for evaluation of level of service in pedestrian facilities" Transportation Research Part A: General, 21(3), pp.223-234. https://doi.org/10.1016/0191-2607(87)90016-1

Nag, D., Goswami, A.K., Gupta, A. and Sen, J., (2020) "Assessing urban sidewalk networks based on three constructs: a synthesis of pedestrian level of service literature" Transport reviews, 40(2), pp.204-240. https://doi.org/10.1080/01441647.2019.1703841

Petritsch, T.A., Landis, B.W., McLeod, P.S., Huang, H.F., Challa, S., Skaggs, C.L., Guttenplan, M. and Vattikuti, V., (2006) "Pedestrian level-of-service model for urban arterial facilities with sidewalks" Transportation Research Record, 1982(1), pp.84-89. https://doi.org/10.1177/0361198106198200111

Rahimi, M., (2019) "Evaluation of pedestrian level of service and users' satisfaction on selected pedestrian sidewalks in downtown Walnut Creek".

Rani, K., Boora, A., & Parida, M. (2021) "Statistical Analysis for Assessing the Built Environment Walkability of an Urban Area", *Eur. Transp./Trasporti Eur, 82*(1). https://doi.org/10.48295/ET.2021.82.1

Rani, K., Boora, A., Bivina, R.G. and Parida, M., (2018) "Which factors affect "walkability" of pedestrians on sidewalk in Indian cities" Proceedings of the Eastern Asia Society for Transportation Studie, 11.

Rossetti, S., Caselli, B., Stabile, F., & Carra, M. (2024) "How do SUMPs Consider Factors Influencing Walkability and Cyclability? A Review of Literature and Planning Tools" *Eur. Transp./Trasporti Eur, 97*, 1-11. https://doi.org/10.48295/ET.2024.97.9

Sahani, R. and Bhuyan, P.K., (2020) "Modelling pedestrian perspectives in evaluating satisfaction levels of urban roadway walking facilities" Transportation research procedia, 48, pp.2262-2279. https://doi.org/10.1016/j.trpro.2020.08.289

Said, M., Abou-Zeid, M. and Kaysi, I., (2017) "Modeling satisfaction with the walking environment: the case of an urban university neighborhood in a developing country" Journal of Urban Planning and Development, 143(1), p.05016009. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000347

Sovani, S., (2020) "Spatial analysis of sidewalks and students' neighbourhood mobility in Mumbai metropolitan region" Transactions, 42(1), p.105.

Televska, J.B. and Todorova, M.M., (2012) "Contribution to sidewalk pedestrian level of service analysis" Transport Problems, 7(3), pp.5-13.

Tira, M., Pezzagno, M., & Richiedei, A. (Eds.). (2020) "*Pedestrians, Urban Spaces and Health", Proceedings of the XXIV International Conference on Living and Walking in Cities (LWC, September 12-13, 2019, Brescia, Italy)*. CRC Press. https://doi.org/10.1201/9781003027379

Ujjwal, J. and Bandyopadhyaya, R., (2023) "Development of Pedestrian Level of Service (PLOS) model and satisfaction perception rating models for pedestrian infrastructure for mixed land-use urban areas" Transportation, 50(2), pp.355-381.

Wang, W., Li, P., Wang, W. and Namgung, M., (2012) "Exploring determinants of pedestrians' satisfaction with sidewalk environments: Case study in Korea" *Journal of Urban Planning and Development*, *138*(2), pp.166-172. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000105

1

Acknowledgements

The authors wish to express their gratitude to Dr. B.R Kadali (Assistant Professor in NIT Warangal) for his valuable suggestions and help during the data collection process in the city of Hyderabad.