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# Identification of Factors Influencing Pedestrian Perceived Safety and Satisfaction Level Using Ordered Logit Models in an Indian Midsized City

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**ABSTRACT**

In Indian cities, pedestrian fatalities and injuries have emerged as significant concerns. However, obtaining consistent and reliable crash information poses a significant challenge, particularly in mid-sized Indian cities. In this framework, this study aims to identify and quantify the critical factors influencing pedestrian perceived safety and satisfaction levels in a mid-sized Indian city with respect to diverse land use patterns. A dataset comprising perceptions of 2112 pedestrians regarding 'safety' and 'satisfaction level' has been collected and analyzed across six major intersections characterized by three distinct land use patterns—religious places, commercial areas, and educational hubs—in the central business district area of Patiala city, Punjab, India. With the help of ordered logit models, it has been concluded that the predominant land use pattern, the presence of a pedestrian signal, carriageway width, presence of a curve section at an intersection, vehicular speed, average value of time-to-collision (TTC) at the junction, pedestrian's gender and educational background, and trip purpose significantly affect pedestrians' perceived safety and satisfaction levels. The model outcomes are further constructively utilized to frame suitable policy interventions and recommend remedial measures to enhance pedestrian safety in Indian cities and comparable cities in other low- and middle-income countries (LMICs).

## 1. INTRODUCTION

Walking is an essential mode of transportation for a sustainable transportation system since it is suitable for short-distance travel, access to and egress from motorized transit, and recreational purposes. Pedestrianism has a number of advantages, including a decrease in energy use and emissions, improve public health, and create of community- or business-friendly roads. Despite the considerable advantages of pedestrianism, pedestrian fatalities and injuries resulting from road traffic crashes pose significant challenges in Indian cities [1]. Pedestrian deaths account for more than 50% of all traffic fatalities in Indian cities [1]. Therefore, prioritizing pedestrian safety is essential for reducing the fatalities caused by traffic crashes.

Previous studies on pedestrian safety have predominantly focused on the impact of road geometrics and traffic characteristics on crash frequency and severity [2-5]. Additionally, existing literature highlights the importance of built environments in shaping pedestrians' attitudes and crossing behavior [1].

In recent years, several studies conducted in urban India have concentrated on identifying pedestrian risk factors by developing safety performance functions [1, 6-9]. Studies have also employed various proactive tools and techniques to analyze pedestrians' risky crossing behavior in the Indian urban environment [10-14]. Furthermore, several studies have aimed to establish systematic frameworks for evaluating perception-based pedestrian safety assessment and levels of service in the context of Indian urban crosswalks [15-17]. Mukherjee and Mitra [18] conducted a comparative study on pedestrian crossing behavior and risk perception across intersections of varying safety levels in Kolkata city, India. A few studies have examined pedestrian signal violation behavior and its implications for safety in Indian metropolitan areas [8, 19]. In a recent study, Mukherjee and Mitra [14] introduced a framework to identify critical urban intersections through a blend of proactive and reactive approaches. The method outlined in this study combines an analysis of historical crash data, examination of pedestrian-vehicular conflicts (pedestrian-vehicular post-encroachment time), and assessment of pedestrians' risk perception concerning the built environment and traffic parameters. Hussain et al. [20] introduced an integrated VISSIM-SSAM approach to anticipate and alleviate pedestrian collisions and severity at urban crossings in India.

Despite several empirical investigations, a significant knowledge and methodological gap still needs to be addressed to promote pedestrian safety in Indian cities. Firstly, the previous studies in urban India have mostly looked at the major Indian cities. The findings documented from the studies conducted in high-income countries [21-22] and Indian metropolitans [8, 14, 16, 23] may not be directly transferable to a mid-sized Indian city as the road environment is substantially dissimilar along with road users' attitudes, awareness, and behavior [11-14]. Secondly, obtaining reliable and satisfactory crash data is a significant challenge in mid-sized cities [24]. Hence, developing a safety performance function may not be feasible in most mid-sized cities in India. Thirdly, studies that have focused exclusively on identifying pedestrian risk factors in mid-sized Indian cities with respect to different land use patterns are scarce. However, pedestrian activity and risk perception are expected to vary with respect to land use patterns, and this variation will further affect the perceived safety and satisfaction level. Fourthly, prior studies that have simultaneously investigated the effects of road geometrics, traffic parameters, and sociodemographic characteristics on pedestrians' perceived safety and satisfaction levels in a single study are rare in pedestrian safety literature, specifically in the context of urban India. Therefore, it is imperative to examine pedestrian safety and satisfaction levels with respect to different land use patterns under mixed traffic conditions, principally focusing on mid-sized Indian cities.

In this context, the current study aims to identify and estimate the key factors influencing pedestrians' perceived safety and satisfaction levels across various land use patterns in a mid-sized Indian city, employing suitable statistical tools and techniques. To accomplish the research objectives, data on the perceptions of 2112 pedestrians regarding 'safety' and 'satisfaction level' were collected and analyzed across six major intersections with diverse land use patterns located in the central business district (CBD) area of Patiala city, Punjab, India. With the help of ordered logit models, the impact of road geometrics, road infrastructure, land use patterns, traffic exposures, operational parameters, and pedestrians' sociodemographic characteristics on pedestrian perceived safety and satisfaction level has been examined. Afterward, the model results were favorably exploited to formulate a set of policy interventions and endorse suitable countermeasures to improve pedestrian crossing behavior and safety at urban intersections in India and similar cities in other low- and middle-income countries (LMICs).

The present paper contributes significantly to the pedestrian safety literature in five key ways. Firstly, it provides a focused examination of pedestrian safety assessment within the unique context of an Indian mid-sized city. This targeted approach offers valuable insights into the specific challenges and dynamics of pedestrian safety in this urban setting. Secondly, the study evaluates pedestrian safety and satisfaction levels across different land use patterns, recognizing that pedestrian activity and risk perception may vary accordingly. By considering these variations, the study enhances the understanding of the factors influencing pedestrian perceived safety and satisfaction levels. Thirdly, the methodology employed in this study serves as a proactive tool for identifying pedestrian risky zones and understanding the critical factors impacting pedestrian safety and satisfaction levels, especially in scenarios where reliable crash data are unavailable for developing safety performance functions. Fourthly, the study stands out by simultaneously investigating the effects of road geometrics, traffic parameters, and sociodemographic characteristics on pedestrians' perceived safety and satisfaction levels, specifically focusing on the Indian mid-sized city context. This comprehensive approach provides an understanding of the multifaceted factors influencing pedestrian safety. Finally, the conclusions drawn from this study offer actionable insights for engineers, urban planners, policymakers, and designers, providing clear guidance on strategies to enhance pedestrian safety in India and other nations with similar road conditions and pedestrian activities. By addressing these key aspects, the present paper significantly contributes to advancing the knowledge and improving pedestrian safety practices on a global scale.

## 2. LITERATURE REVIEW

An individual's knowledge of the risk associated with various traffic situations is referred to as their perception of traffic risk. Road users' risk perception provides important evidence of the possible risk of road traffic crashes, which may be advantageous in detecting the root causes of crashes. Traffic risk perception is also valuable for identifying hazardous locations at the road network level without reliable crash data [18]. In addition, actual crash data only affords crash incidence and severity details. Alternatively, traffic risk perception deals with road users' actual difficulties, challenges, and requirements.

Papadimitriou et al. [25] studied pedestrian attitudes, perceptions, and behavior based on a questionnaire survey conducted in 19 European nations. With the help of Principal Component Analysis, a group of variables reflecting pedestrians' specific attitudes and behavioral aspects was recognized. Based on the risk perception data collected from the five countries, Azik et al. [26] concluded that structural variations in the size and structure of the country, socioeconomic appearances, and road network features significantly impact risk perceptions. Dinh et al. [27] examined associations between attitudes toward road safety, risk perception, and pedestrian behavior in Vietnam and found that road users with higher risk perception engaged in safe crossing behavior.

Several past studies have utilized risk perception techniques to examine the pedestrian level of service (LOS). For example, Kadali and Vedagiri [28] evaluated pedestrian-perceived LOS at unsignalized (unprotected) crosswalks with varying land use patterns under Indian urban mixed traffic conditions. The study concluded that the perceived LOS of pedestrians was considerably influenced by the kind of land use, the number of vehicles they interact with, the median width, and the number of lanes. Further, based on the case study conducted in Ioannina, Greece. Georgiou et al. [29] acknowledged that perceived comfort is an essential determinant in assessing LOS. Nag et al. [30] conveyed a comprehensive approach to evaluating pedestrians' satisfaction levels and ascertaining whether the elements that increase user satisfaction result in a shift in user behavior.

Researchers have recently been motivated to develop safety performance functions to measure pedestrian safety [8, 14, 31]. Avinash et al. [32] utilized the pedestrian safety margin concept to identify the critical factors influencing the possibility of pedestrian-vehicular crashes at urban midblock crossings in Mumbai, Chandigarh, and Ahmedabad cities. Rankavat and Tiwari [33] studied relationships between real and perceived crash risk in Delhi and found a converse correlation between them. Mukherjee and Mitra [16] identified the critical factors influencing pedestrians' perceived crossing difficulty at high crash-prone crossings in Kolkata. The study also found an optimistic relationship between pedestrian crossing difficulty and police-reported crash data.

Even though several past studies investigated pedestrian safety issues in urban India based on safety performance functions [1, 8, 9, 31], pedestrian vehicular conflict analysis [12, 13, 32], and risk perception techniques [16, 33], the studies are primarily restricted to the Indian metropolises. However, pedestrian crossing behavior, attitude, and road safety awareness might be very dissimilar in a mid-sized Indian city. Hence, it is essential to conduct a dedicated study focusing solely on pedestrian safety issues in a typical mid-sized Indian city. Furthermore, previous researchers have not adequately explored the impact of different land use patterns on pedestrian risk perception in the context of mid-sized Indian cities. However, land use patterns play a crucial role in influencing pedestrians' risk-taking attitudes and actual crash occurrences [1, 8, 14]. In this context, the present paper investigates the factors influencing pedestrians' perceived safety and satisfaction levels at six major intersections characterized by three predominant land-use types (i.e., commercial, religious, and educational) under mixed traffic conditions in a typical mid-sized city in India.

## 3. RESEARCH METHODOLOGY

To achieve the research goals of this study, a four-step methodology was followed (Figure 1). The research methodology was simple and easy to follow. The current research entails (a) selection of intersections, (b) survey and data collection (i.e., road inventory survey, spot speed survey, videography survey, and questionnaire survey), (c) descriptive analysis and development of statistical models to identify the significant factors influencing pedestrians' perceived safety and satisfaction levels, (d) formulation of suitable countermeasures and policy interventions to improve pedestrian safety and comfort at urban intersections in the context of Indian mid-size cities. The research methodology was chosen in such a way that it will be able to provide a compressive idea of pedestrian risk factors and factors influencing their satisfaction levels. The methodology employed was straightforward, easily understandable, and readily transferable to the other provinces of urban India. A comparable research methodology was also adopted by past researchers [1, 16].

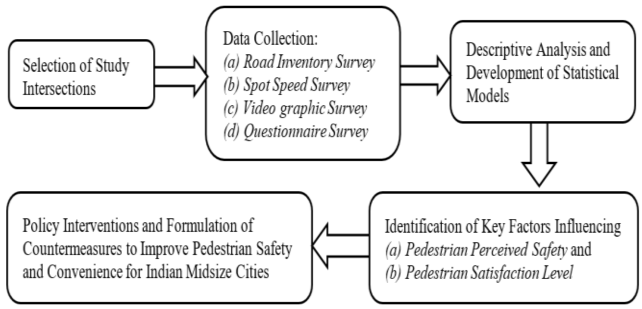


**Figure 1.** Study methodology

### 3.1 Selection of study intersections

To identify the crucial variables influencing pedestrians' perceptions of safety and satisfaction levels, Patiala city in Punjab was selected as a case study. Patiala, situated in southeastern Punjab, northwestern India, holds the distinction of being the fourth-largest city in the state and serves as the administrative capital of Patiala district. Encompassing a total area of 365 square kilometers, Patiala presents a diverse urban landscape ideal for studying pedestrian safety dynamics.

Besides, according to the "Accident Black Spot Identification and Rectification Program on Various Highway/Roads of Punjab: 2021," a total of 55 black spots exists in Patiala. The presence of this alarming number of black spots underscores the urgent need for focused attention to protect road users and provide a safe road environment in Patiala city [34].

To achieve the present research goal, six major intersections with different land-use types were selected from the CBD area of Patiala city (Figure 2). The selected intersections have diverse land-use types such as (a) commercial zones, (b) religious places, and (c) educational hubs with varied road geometrics and traffic characteristics. However, the land-use patterns are tough to classify as diverse activities that typically occur in mid-sized Indian cities [20]. The current study defines the land-use pattern based on nearby activities (within 100 meters) corresponding to the intersection crossing [14]. In all the selected locations, there is a significantly high volume of pedestrian crossings, leading to frequent and critical interactions between pedestrians and motorists.


Site 1: Dukh Nivaran Sahib Chowk


Site 2: Fountain Chowk Patiala


Site 3: Leela Bhawan Chowk


Site 4: Nabha Road Chowk


Site 5: Thikriwala Chowk


Site 6: TIET Chowk

**Figure 2.** Study intersections

### 3.2 Survey and data collection

In this study, (a) road inventory survey, (b) spot speed survey, (c) video graphic survey, and (d) questionnaire survey were conducted by a group of road safety experts and surveyors. The road inventory survey comprised several parameters related to road geometrics, sight distance, road signage and marking, traffic signal parameters, roadside adjacent land use patterns, pavement surface conditions, traffic movement characteristics, etc.

A spot speed survey was carried out at each study location to estimate the approaching vehicle speed at an intersection. Speed data were collected from at least 30 samples for each vehicle category to assess the 85$^{th}$ percentile speed at the site [8].

Subsequently, video recording was conducted at each intersection to estimate the daily average traffic volume and to examine pedestrian-vehicular interaction [16]. The video recording and data extraction were conducted for six hours, from 8 am to 11 am and from 5 pm to 8 pm, to capture both peak and off-peak traffic periods. The classified traffic volume, including turning movements, was manually counted by a team of well-trained research associates. Additionally, to study pedestrian-vehicular interaction, the average time-to-collision was extracted from the video images [35].

A questionnaire survey was conducted to examine pedestrians' perception of 'safety' and 'satisfaction' levels. A group of experienced survey experts directed the onsite questionnaire survey for six hours between morning, 8 am and 11 am, and evening, 5 pm and 8 pm (same as the video recording time phase). The questionnaire survey included information about pedestrians' sociodemographic characteristics, trip purpose, and intended mode of transportation immediately after the crossing. The meaning and importance of each question of the questionnaire were personally explained to each pedestrian to get their opinions on (a) safety and (b) satisfaction with the overall road environment of the intersection on a scale of "1 to 6", where 1 represents "highly safe/highly satisfied" conditions and 6 represents "highly unsafe/highly unsatisfied." The questionnaire form was prepared in English and regional languages (Hindi and Punjabi) to understand the survey respondents better. Further, it should be mentioned that based on pedestrians' willingness to participate in the questionnaire survey, survey participants were chosen, and pedestrians' responses were recorded immediately after the crossing. A total of 2112 pedestrians were surveyed from six intersections. The sample size utilized in this study is greater than the minimum sample size to get reliable results [36].

To assess *pedestrian satisfaction level* and *safety perception*, the current study utilized a 6-point scale to compare *pedestrian-perceived safety* and *satisfaction levels* with the standard level of service practices (i.e., LOS A, LOS B, LOS C, LOS D, LOS E, LOS F) as suggested in the Highway Capacity Manual and IRC 103: 2012 (i.e., *Guidelines for Pedestrian Facilities*). The use of pedestrian risk perception and satisfaction level on a 6-point scale is also well-established in the prior research conducted in India and other developing nations [37, 38].

Table 1 provides descriptions of these variables. The number of survey respondents tabulated along with the predominant land use pattern at each intersection is shown in Table 2. Additionally, Table 2 shows each study site's average perceived safety and satisfaction scores. If the perceived safety or satisfaction for '$N_1$' pedestrian (first pedestrian) is $PS_1$, '$N_2$' Pedestrian (second pedestrian) is $PS_2$, '$N_3$' Pedestrian (third pedestrian) is $PS_3$, and '$N_n$' pedestrian ($N_n^{th}$ pedestrian) is $PS_n$; then the average safety or satisfaction ($PS_{avg}$) of the intersection 'i' is:

$$PS_{avg} = \frac{PS_1 + PS_2 + PS_3 + \cdots \ldots + PS_n}{n} \quad (1)$$

where, n is the total number of the survey respondents (i.e., n = $N_1 + N_2 + N_3 + \ldots + N_n$) at a particular intersection 'i' during the survey period. A specific site's average safety and satisfaction score indicates the overall safety performance and lacuna of pedestrian infrastructure and traffic operational issues. Sociodemographic information, trip purpose, and intended mode of transportation of the survey respondents have also been presented in Figure 3.

**Table 1.** Description of variables

| Variable Name | Description | Type of Variable | Source of Data |
|---|---|---|---|
| Junction type [18] | a) Signalized<br>b) Unsignalized | Categorical | Road Inventory Survey |
| Number of legs [1] (approaches) | a) Three<br>b) Four<br>c) More than four<br>d) Roundabout | Categorical | Road Inventory Survey |
| Land use type [14] | The current study defines the land-use pattern based on nearby activities (within 100 meters) corresponding to the intersection crossing. The predominant land use types considered in the present study are as follows:<br>a) Office area<br>b) Residential area<br>c) Educational area<br>d) Commercial area<br>e) Religious area | Categorical | Road Inventory Survey |
| Pavement Surface conditions [1] | The pavement surface condition was evaluated by road safety experts and classified into two main groups:<br>a) Good<br>b) Poor | Categorical | Road Inventory Survey |
| Road alignment | a) Straight<br>b) Curved | Categorical | Road Inventory Survey |
| Sight distance [1] | a) Adequate: if clear visibility is available at the junction<br>b) Inadequate: if clear visibility is obstructed by road geometrics/man-made structure | Categorical | Road Inventory Survey |
| Carriageway width (meter) | Width of the major and minor roads, including median and refuge islands | Continuous | Road inventory survey |
| | Number of lanes | Continuous | Road inventory survey |
| Type of road [1] | a) Divided<br>b) Undivided carriageway | Categorical | Road inventory survey |
| Traffic movement | a) One way<br>b) Two way | Categorical | Road inventory survey |
| On-street parking | a) Present<br>b) Absent | Categorical | Road inventory survey |
| Zebra crossing [18] | a) Present<br>b) Absent | Categorical | Road inventory survey |
| Width of zebra crossing | Width of the zebra crossing at a major and minor road (if zebra crossing is present at teh minor road) | Continuous | Road inventory survey |
| Sidewalk [18] | a) Present<br>b) Absent | Categorical | Road inventory survey |
| Width of the sidewalk (i.e., width of the pedestrian footpath) [10] | Width of the sidewalk at a major and minor road (if present) | Continuous | Road inventory survey |
| Encroachment of Sidewalk [18] | Roadside encroachment due to the street vendors or hawkers on the sidewalk (Measured in percentage) | Continuous | Road Inventory Survey |

| | | | |
|---|---|---|---|
| Designated Bus Stop at Junction (i.e., the presence of a designated bus stop close to the junction) [18] | a) Present<br>b) Absent | Categorical | Road Inventory Survey |
| The carriageway is blocked by the stopped bus [14] | a) Yes<br>b) No | Categorical | Videography Survey |
| The overtaking tendency of vehicles behind the stopped bus (it was manually extracted from the video images by the project associates in the laboratory) [18] | a) Present<br>b) Absent | Categorical | Videography Survey |
| Adequate Street Light [14] | a) Present: If the street light is present and adequate<br>b) Absent: if the street light is not present at an intersection or it is not adequate | Categorical | Road Inventory Survey |
| Central Refuge Island | a) Present<br>b) Absent | Categorical | Road Inventory Survey |
| Median Opening | Width of the median gap (measured in meters) | Continuous | Road Inventory Survey |
| Pavement Marking (i.e., edge line, center line marking, etc.) [14] | a) Present: if pavement marking with clear visibility exists<br>b) Absent: if pavement marking is not present or faded and difficult to detect by a road users | Categorical | Road Inventory Survey |
| Stop Line [14] | a) Present<br>b) Absent | Categorical | Road Inventory Survey |
| Pedestrian Sign [8] | a) Present<br>b) Absent | Categorical | Road Inventory Survey |
| Road Signage (i.,e., speed limit, pedestrian crossing, bus stop, junction ahead) [8] | a) Present<br>b) Absent | Categorical | Road Inventory Survey |
| Cycle Length (sec.) [8] | Total cycle length of the intersection (measured in seconds) | Continuous | Videography Survey |
| Phasing Time (sec.) [8] | Phase timing of the traffic signal (measured in seconds) | Continuous | Videography Survey |
| Pedestrian Phase [8] | a) Present<br>b) Absent | Categorical | Videography Survey |
| Timing of Pedestrian Phase (sec.) [8] | Pedestrian phase timing of the traffic signal (measured in seconds) | Continuous | Videography Survey |
| Pedestrian Vehicular Interaction (it was manually extracted from the video images by the project associates in the laboratory) [35] | Pedestrian-vehicular interaction was measured in terms of Time-To-Collision (TTC), *the time it would take for a collision to occur at an instant speed, distance, and acceleration allied with the driver's vehicle and the nearest lead vehicle* [35] | Continuous | Videography Survey |
| Average Daily Traffic (ADT) [1] | The logarithm of ADT was manually estimated based on the video data extraction [1] | Continuous | Videography Survey |
| Gender of the pedestrian | a) Male<br>b) Female | Categorical | Questionnaire Survey |
| The Age Group of the pedestrian [1] | a) Up to 18<br>b) 18 to 49<br>c) 50 and above | Categorical | Questionnaire Survey |
| Educational Qualification of the Pedestrian [8] | a) Nil<br>b) Primary<br>c) Secondary<br>d) Graduation<br>e) Post-Graduation | Categorical | Questionnaire Survey |
| Employment Status of the Pedestrian [8] | a) Unemployed<br>b) Office worker<br>c) Industrial worker<br>d) Business<br>e) Student<br>f) Others | Categorical | Questionnaire Survey |
| Purpose of Trip of the Pedestrian [8] | Pedestrian's trip purpose was classified into 7 categories, namely,<br>a) Education<br>b) Business<br>c) Job<br>d) Entertainment and religious trip<br>e) Shopping<br>f) Medical treatment<br>g) Others | Categorical | Questionnaire Survey |

| | | | |
|---|---|---|---|
| Pedestrian's Intended Mode of Transport Immediately After Crossing [8] | a) Bus<br>b) Paratransit mode<br>c) Own vehicle | Categorical | Questionnaire Survey |
| Pedestrian Perceived Safety [8, 16]<br>(*Each pedestrian was requested to provide their response on a 6-point scale, where 1 indicates highly safe and 6 indicates highly unsafe*) | a) Highly safe<br>b) Safe<br>c) Moderate<br>d) Not safe<br>e) Unsafe<br>f) Highly unsafe | Ordinal | Questionnaire Survey |
| Pedestrian Perceived Satisfaction Level [8, 16]<br>(*Each pedestrian was requested to provide their response on a 6-point scale, where 1 indicates highly satisfied and 6 indicates highly unsatisfied with the existing road environment*) | a) Highly satisfied<br>b) Satisfied<br>c) Moderate<br>d) Not satisfied<br>e) Dissatisfied<br>f) Highly unsatisfied | Ordinal | Questionnaire Survey |

**Table 2.** Land use pattern of selected intersections

| Sr. No. | Location Name | Predominant Land-Use Type | Sample Size | Average Safety Score | Average Satisfaction Score |
|---|---|---|---|---|---|
| Site 1 | Dukh Nivaran Sahib Chowk | Religious Place | 670 | 4.2 | 4.3 |
| Site 2 | Fountain Chowk | Commercial | 219 | 4.1 | 4.1 |
| Site 3 | Leela Bhawan | Commercial | 305 | 4.0 | 3.6 |
| Site 4 | Nabha Road Chowk | Educational Hub | 292 | 2.2 | 2.3 |
| Site 5 | Thikriwala Chowk | Commercial | 340 | 4.2 | 3.8 |
| Site 6 | TIET Chowk | Educational Hub | 286 | 3.1 | 2.6 |

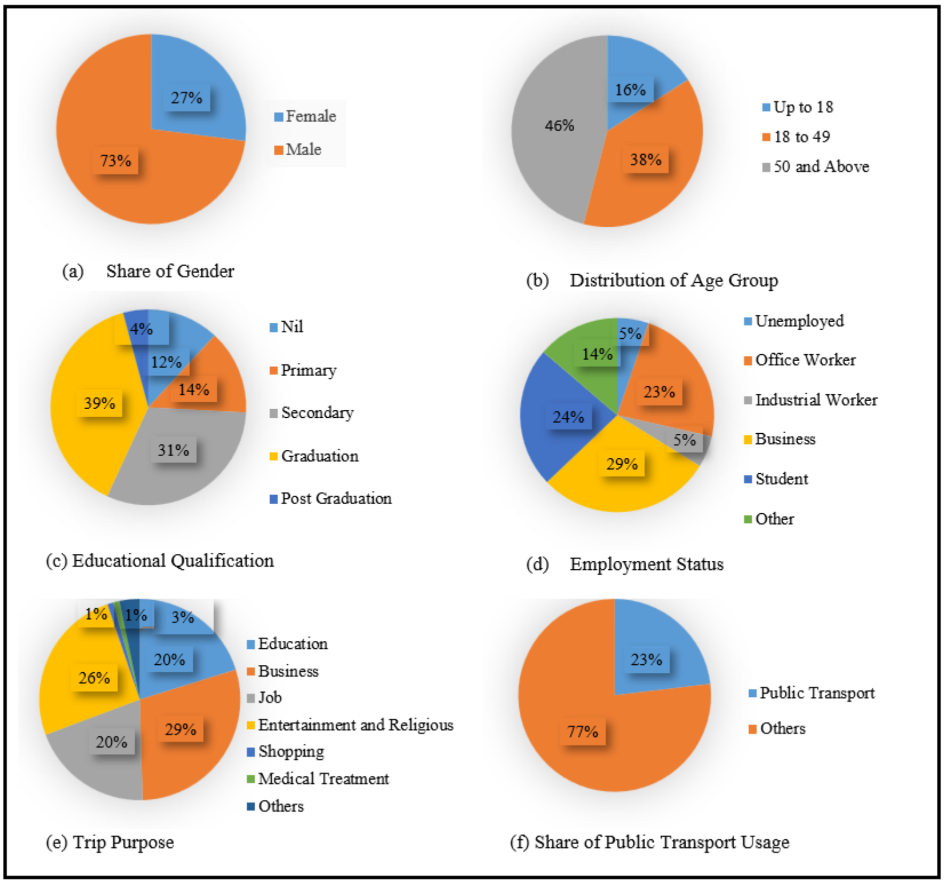


**Figure 3.** Descriptive statistics of questionnaire survey

### 3.3 Statistical analysis and modelling approach

The ANOVA technique was applied to recognize the variation in pedestrians' perception across different land use types [18]. Afterward, Spearman's rank correlation test was performed to examine the significant correlations between road geometrics, land use patterns, traffic exposures, operational parameters, pedestrians' sociodemographic characteristics, and pedestrians' perceived safety and satisfaction levels [15].

Establishing the relationship between the level of safety/satisfaction and significant variables associated with road geometries, land use patterns, traffic parameters, and sociodemographic characteristics of pedestrians, the ordered logit (OL) model is considered a best practice [39]. This model helps identify the critical factors influencing pedestrian-perceived crossing safety and satisfaction levels (ordered as well as discrete data) [15]. The equation of the OL model is as follows [39]:

$$z = X\beta + \varepsilon_i \tag{2}$$

where, the model coefficient is β, and the model error is $\varepsilon_i$, X is a vector of variables that defines the discrete ordering for n observations. For each observation, this equation describes the observed ordinal data, *y*, as

$$y = 1 \quad \text{if } z \le \mu_1 \text{ [Highly safe/highly satisfied]} \tag{3a}$$

$$y = 2 \quad \text{if } \mu_1 < z \le \mu_2 \tag{3b}$$

$$y = 3 \quad \text{if } \mu_2 < z \le \mu_3 \qquad y = \ldots\ldots\ldots \tag{3c}$$

$$y = 6 \quad \text{if } z \ge \mu_{M-1} \text{ [Highly unsafe/highly unsatisfied]} \tag{3d}$$

Here, μ is a threshold parameter. For the OL model, the probability value was estimated using the following formula:

$$P(Y_i > J) = \frac{\exp(X_i\beta - \mu_j)}{1 + [\exp(X_i\beta - \mu_j)]},\ j = 1, 2, 3\ldots\ldots, M\text{-}1, \tag{4a}$$

which implies

$$P(Y_i = 1) = 1 - \frac{\exp(X_i\beta - \mu_1)}{1 + [\exp(X_i\beta - \mu_1)]} \tag{4b}$$

$$P(Y_i = j) = \frac{\exp(X_i\beta - \mu_{j-1})}{1 + [\exp(X_i\beta - \mu_{j-1})]} - \frac{\exp(X_i\beta - \mu_1)}{1 + [\exp(X_i\beta - \mu_1)]} \quad j = 2, \ldots, M\text{-}1 \tag{4c}$$

$$P(Y_i = M) = \frac{\exp(X_i\beta - \mu_{M-1})}{1 + [\exp(X_i\beta - \mu_{M-1})]} \tag{4d}$$

Using the log-likelihood ratio test, the proposed OL model's goodness of fit was estimated [39]. The log-likelihood ratio index is calculated to measure the overall goodness-of-fit of the models [39].

$$\rho^2 = 1 - \frac{LL(\beta)}{LL(0)} \tag{5}$$

### 3.4 Formulation of countermeasures and policy interventions

Identifying effective countermeasures to reduce the likelihood of traffic crashes and create a safe road environment is essential for enhancing pedestrian safety. Drawing from the present study's findings, several corrective measures and action plans were proposed in this paper to improve pedestrian safety.

## 4. RESULTS AND DISCUSSION

### 4.1 Observations from field survey

The questionnaire survey findings revealed that pedestrians perceived significantly lower levels of safety and satisfaction at the religious place compared to other locations (Figure. 4). Due to the lack of pedestrian signals along the wider roadway section and non-standard markings of zebra crossing at selected religious locations, pedestrians rated safety and satisfaction as significantly lower. Alternatively, pedestrians perceived higher safety and satisfaction levels near educational hubs. At educational hubs, standard zebra crossings and dedicated pedestrian phases are present, which causes pedestrians to perceive more excellent safety and satisfaction levels compared to commercial and religious locations.

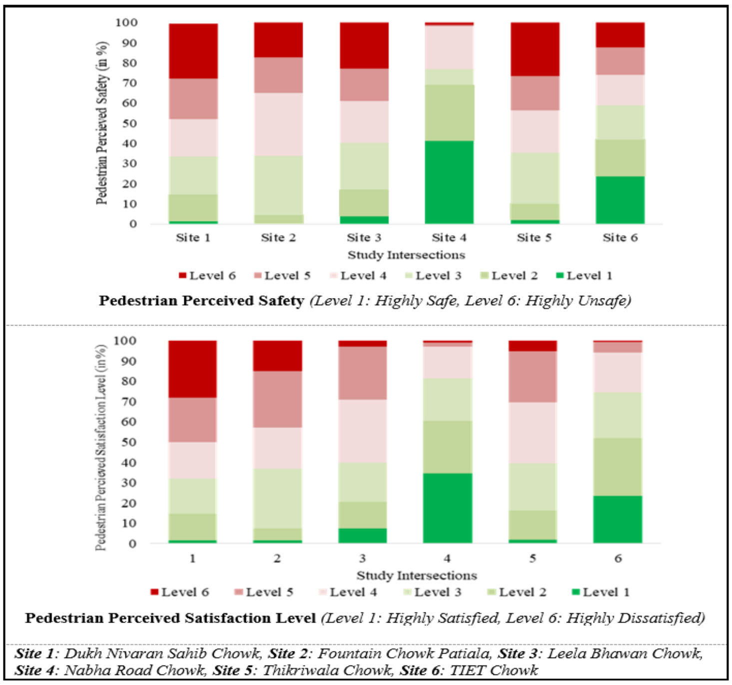


**Figure 4.** Responses of pedestrian perceived safety and satisfaction level

**Table 3.** ANOVA test results

| Variables | Null Hypothesis | Sample Size | f-Statistics | p-Value | Remarks |
|---|---|---|---|---|---|
| Perceived Safety | Pedestrian perceived safety doesn't vary with land use type | 2112 | 7.57 | 0.000 | Reject |
| Perceived Satisfaction Level | Pedestrian perceived satisfaction doesn't vary with land use type | 2112 | 6.59 | 0.000 | Reject |
| ln(ADT) | Vehicular volume doesn't vary with land use type | 6 | 1.51 | 0.143 | Not Reject |
| 85$^{th}$ Percentile Speed | Vehicular speed doesn't vary with land use type | 248 | 21.38 | 0.000 | Reject |
| Pedestrian-Vehicular Interaction | TTC doesn't vary with land use type | 119 | 8.80 | 0.000 | Reject |

**Table 4.** Correlation outcomes of correlation tests

| Characteristics | Variable | Perceived Safety | Perceived Satisfaction Level |
|---|---|---|---|
| Junction Type | Signalization | -0.240*** | -0.139*** |
| Police Personnel | Presence of onsite traffic police | -0.106*** | -- |
| Land Use Type | Educational | -0.055** | -0.180*** |
| | Commercial | 0.024* | 0.039* |
| | Religious place | 0.077*** | 0.063*** |
| Presence of Sight Distance | Presence of adequate sight distance at a junction | -0.083*** | -0.079*** |
| Carriageway Width (meter) | Road width | 0.138*** | 0.093** |
| Curved Road | Presence of a curve at the junction | 0.109*** | 0.057* |
| On-street Parking | Presence of on-street parking | 0.083*** | 0.112*** |
| Crossing Facility | Presence of zebra crossing | -0.085*** | -0.162*** |
| Sidewalk | Presence of sidewalk | -0.066** | -0.063** |
| | Sidewalk width | -0.048* | -0.104*** |
| Bus Stop at Junction | Absence of commuter facility at the bus stop | 0.196*** | 0.167*** |
| The Carriageway is Blocked by the Stopped Bus | The carriageway is blocked by a stopped bus at a junction | 0.055*** | 0.108*** |
| Central Refuge Island (CRI) | Presence of CRI at the junction | -0.019* | -0.083** |
| Pavement Marking | Presence of adequate pavement marking | -0.0071*** | -0.086*** |
| Cycle Length (sec) | Overall cycle length of the junction | -0.082*** | -0.082*** |
| Timing of Pedestrian Phase (sec) | Pedestrian phase timing | -0.103*** | -0.149*** |
| Speed | 85$^{th}$ percentile speed of the junction | 0.131*** | 0.184*** |
| Pedestrian Vehicular Interaction | Average TTC at the junction | -0.058*** | -0.068*** |
| Gender | Female | 0.043** | -- |
| Educational Qualification | Post-graduation and above | -0.059** | -0.031** |
| Employment Status | Unemployed | 0.089** | 0.078** |
| | Business | 0.063** | 0.059** |
| | Students | -0.033** | -0.031** |
| Purpose of Trip | Business | 0.155*** | 0.149*** |
| | Job | -- | 0.104*** |
| | Education | -0.411*** | -0.503*** |
| | Entertainment and religious | 0.678*** | 0.433*** |
| Pedestrian's Intended Mode of Transport | Public bus | -- | 0.124** |

Note: ***Significant at 99% Confidence Interval; **Significant at 95% Confidence Interval; *Significant at 90% Confidence Interval, -- Not Significant

### 4.2 Descriptive analysis

ANOVA was applied to identify the significant differences in pedestrians' perceptions of safety and satisfaction across different land use patterns. The test results indicate pedestrian perceived safety and satisfaction levels, 85th percentile speed, and the average TTC values are not uniform across different land use patterns (Table 3). However, average daily traffic volume doesn't vary significantly with diverse land use types.

The Spearman Rank correlation test was also employed to investigate the effects of each independent variable on pedestrians' perceptions of safety and satisfaction, and the test findings are reported in Table 4. It was identified that the existence of traffic signals, adequate sight distance, wider zebra crossings, and sidewalks have a significant and optimistic impact on pedestrians' perception of a higher safety and satisfaction level. Conversely, lack of pavement marking and road signage, lack of designated bus stop facilities, higher vehicular speed, and a lower TTC value negatively influence the pedestrian perception of safety and satisfaction levels. Regarding pedestrians' sociodemographic aspects, poor educational background, frequency of unemployed persons, and pedestrian's trip purpose substantially affect their perception.

### 4.3 Model outcomes

Two ordinal logistic (OL) models were developed to identify the critical factors influencing respondents' perceptions of safety and satisfaction. To mitigate multicollinearity issues among independent variables, only a select few were included in the OL modeling, chosen for their lower correlations. Initially, only uncorrelated independent variables showing a high correlation with the dependent variable (perceived safety or satisfaction level) were incorporated into the model. Subsequently, during iterative testing, insignificant variables or those with implausible signs were systematically eliminated. Among several competing models, those deemed "best-fitted" were selected based on various criteria, including model goodness of fit (i.e., log-likelihood value) and theoretical relevance of variables. The subsequent subsections present the model results and their corresponding discussions. Table 5 and Table 6 present the model outcomes.

The model's outcome indicates that the presence of traffic signals ($\beta = -0.67$, $p<0.01$) and sufficient pedestrian phases ($\beta = -0.20$, $p<0.01$) enhances perceived safety (Table 5). Conversely, curved roads at intersections ($\beta = 0.49$, $p<0.01$) and wider road widths ($\beta = 0.23$, $p<0.01$) are associated with decreased perceived safety. Furthermore, pedestrian-perceived safety is notably lower in commercial ($\beta = 0.22$, $p<0.10$) and religious areas ($\beta = 0.59$, $p<0.10$), whereas it is higher in educational zones ($\beta = -0.20$, $p<0.10$). Intersections with higher vehicle speeds ($\beta = 1.15$, $p<0.01$) and lower Time to Collision (TTC) ($\beta = -4.47$, $p<0.01$) values also negatively affect pedestrians' safety perception ($\beta = -4.47$, $p<0.01$). Female pedestrians generally perceive a higher risk compared to male pedestrians ($\beta = 0.31$, $p<0.01$). Additionally, pedestrians with lower levels of education perceive a higher risk when crossing ($\beta = 0.31$, $p<0.01$). Those making trips for work purposes ($\beta = 0.39$, $p<0.01$), as well as religious or entertainment-related trips ($\beta = 0.92$, $p<0.01$), also perceive a higher risk.

Table 6 shows that reduced pedestrian phase timing ($\beta = 0.74$, $p<0.01$), wider road widths ($\beta = 0.68$, $p<0.01$), lack of zebra crossings ($\beta = 1.67$, $p<0.01$), pavement markings ($\beta = 9.82$, $p<0.01$), and the presence of on-street parking ($\beta = 0.30$, $p<0.01$) are associated with decreased pedestrian satisfaction levels. Conversely, wider sidewalk facilities ($\beta = -4.77$, $p<0.01$) and the presence of wider zebra crossings ($\beta = 61$, $p<0.01$) improve pedestrian satisfaction levels. Pedestrian-perceived satisfaction level is considerably lower in commercial ($\beta = 0.13$, $p<0.10$) and religious areas ($\beta = 0.39$, $p<0.01$), whereas it is higher in educational zones ($\beta = -0.54$, $p<0.01$). Pedestrians also report lower satisfaction levels at intersections with significantly higher average vehicular speeds ($\beta = 1.19$, $p<0.01$). Additionally, pedestrians with lower levels of education express higher dissatisfaction ($\beta = 0.39$, $p<0.01$). Interestingly, pedestrians engaged in religious or entertainment-related trips ($\beta = 1.16$, $p<0.01$) exhibit significantly lower satisfaction levels compared to those on educational trips ($\beta = -0.28$, $p<0.01$). Furthermore, commuters waiting for buses at bus stops also perceive lower satisfaction levels ($\beta = 0.69$, $p<0.01$). In the following subsections, the interpretation of each significant variable is explained in detail, drawing upon prior studies conducted not only in India and other LMICs but also in HICs.

**Table 5.** OL model for pedestrian perceived safety

| Characteristics | Variable | Coefficient | t-Statistics | p-Value |
|---|---|---|---|---|
| Roadway Factors | Presence of Traffic Signal | -0.673 | -8.89 | 0.000 |
| | Pedestrian Phase Timing | -0.208 | -9.01 | 0.000 |
| | Presence of Curved Road | 0.498 | 3.26 | 0.000 |
| | Carriageway Width | 0.236 | 7.67 | 0.001 |
| Land Use Type | Religious Area | 0.593 | 9.25 | 0.000 |
| | Commercial Area | 0.220 | 1.68 | 0.093 |
| | Educational Area | -0.206 | -1.85 | 0.064 |
| Traffic Exposures | $85^{th}$ Percentile Speed at the Site | 1.115 | 9.21 | 0.000 |
| Pedestrian-Vehicular Interaction | Time to Collision | -4.475 | -4.63 | 0.000 |
| Demographics | Female | 0.316 | 2.04 | 0.041 |
| Education Level | Up to Primary Level | 0.312 | 2.74 | 0.006 |
| | Post-Graduation and Above | -0.529 | -2.57 | 0.010 |
| Trip Purpose | Job | 0.390 | 3.63 | 0.008 |
| | Entertainment and Religious | 0.926 | 4.24 | 0.000 |
| | Students | -0.407 | -3.94 | 0.000 |
| Model Summary | Threshold Parameter ($\mu_1$) | | $1.39 (1.77)^{*}$ | |
| | Threshold Parameter ($\mu_2$) | | $1.549 (2.33)^{**}$ | |
| | Threshold Parameter ($\mu_3$) | | $2.987 (4.59)^{***}$ | |
| | Threshold Parameter ($\mu_4$) | | $3.190 (4.16)^{***}$ | |
| | Threshold Parameter ($\mu_5$) | | $3.951 (5.63)^{***}$ | |
| | Sample Size | | 2112 | |
| | Chi-Squared Value ($\chi^2$) | | 57.45 ($p<0.001$) | |
| | Log-likelihood | | -3576.923 | |
| | The goodness of fit ($\rho^2$) | | 0.113 | |

Note: $^{***}$Significant at 99% Confidence Interval; $^{**}$Significant at 95% Confidence Interval; $^{*}$Significant at 90% Confidence Interval

**Table 6.** OL model for pedestrian perceived satisfaction

| Characteristics | Variable | Coefficient | t-Statistics | p-Value |
|---|---|---|---|---|
| Roadway Factors | Pedestrian Phase Timing | -0.747 | -4.60 | 0.000 |
| | Carriageway Width | 0.068 | 3.48 | 0.000 |
| | Presence of Zebra Crossing | -1.671 | -12.34 | 0.000 |
| | Width of Zebra Crossing | -0.613 | -10.77 | 0.000 |
| | Width of Sidewalk | -4.77 | -9.23 | 0.000 |
| | Pavement Marking | -9.824 | -6.16 | 0.000 |
| | On-Street Parking | 0.303 | 3.83 | 0.000 |
| Land Use Type | Religious Area | 0.399 | 10.77 | 0.000 |
| | Commercial Area | 0.137 | 1.72 | 0.085 |
| | Educational Area | -0.544 | -10.60 | 0.000 |
| Traffic Exposures | 85$^{th}$ Percentile Speed of the Site | 1.196 | 6.13 | 0.000 |
| Education Level | Primary | 0.393 | 3.49 | 0.000 |
| Trip Purpose | Education | -0.286 | -2.77 | 0.006 |
| | Entertainment and Religious | 1.167 | 3.39 | 0.000 |
| Mode of Transportation | Bus | 0.698 | 6.64 | 0.000 |
| Model Summary | Threshold Parameter ($\mu_1$) | 1.158 (2.78)*** | | |
| | Threshold Parameter ($\mu_2$) | 1.608 (3.55)*** | | |
| | Threshold Parameter ($\mu_3$) | 3.759 (5.68)*** | | |
| | Threshold Parameter ($\mu_4$) | 4.210 (4.67)*** | | |
| | Threshold Parameter ($\mu_5$) | 5.981 (7.93)*** | | |
| | Sample Size | 2112 | | |
| | Chi-Squared Value ($\chi^2$) | 195.06 ($p<0.001$) | | |
| | Log-likelihood | -3493.594 | | |
| | The goodness of fit ($\rho^2$) | 0.129 | | |

Note: ***Significant at 99% Confidence Interval; **Significant at 95% Confidence Interval; *Significant at 90% Confidence Interval

4.3.1 Roadway factors

The model outcomes indicate the existence of traffic signals with a dedicated pedestrian phase helps improve pedestrians' safety and satisfaction levels. The present finding is consistent with the results documented by past researchers [40, 41]. A study conducted in Montreal, Canada, concluded that pedestrian priority phases reduced injuries, whereas the presence of the green straight arrow increased injuries [42]. In contrast, Quistberg et al. [43] examined the relationship between pedestrian-motor vehicle collisions and the presence of visible traffic signals, pedestrian signals, and signal timing in Lima (Capital of Peru) to determine whether these countermeasures improved pedestrian safety. The study claimed that pedestrian-vehicular collisions were more frequent where signalization was present.

Curved roads at an intersection have a detrimental effect on the pedestrian perception of safety. In general, the presence of a curved section at an intersection blocks the visibility of pedestrians; consequently, they perceive a higher risk of crossing.

Pedestrians generally perceive lesser safety and satisfaction on wider roads. Wider roads have also been linked to a higher risk of fatal pedestrian crashes [44, 45]. Typically, wider roads facilitate faster operating speeds, which may contribute to this perception. Additionally, as the width or the number of lanes of a road increases, pedestrians' crossing time increases, thereby elevating the likelihood of pedestrian-vehicle collisions. A recent report by the World Health Organization (WHO) also emphasized that wider minor roads increase the risk of pedestrian-vehicular crashes [46].

It is also found that the existence of wider zebra crossings, adequate pavement marking, and wider sidewalks are helpful in improving pedestrian satisfaction levels. A study by Mukherjee and Mitra [1] found that the presence of wider and more accessible zebra crossings is beneficial in reducing the frequency of pedestrian fatalities. William et al. [47] also acknowledged that zebra crossings help reduce critical interactions between pedestrians and motorists. Further, there is some evidence that zebra crossing plays a vital role in reducing pedestrian-vehicular critical conflicts at controlled and uncontrolled intersections [48].

The model's outcomes show that having on-street parking close to a junction raises the possibility of pedestrian dissatisfaction. On-street parking makes it difficult for vehicle drivers and pedestrians to see each other clearly, which may be a significant factor in pedestrians' lower safety perception and greater dissatisfaction. Landis et al. [49] and Asadi-Shekari et al. [50] also concluded that the presence of on-street parking significantly affects pedestrian safety and comfort.

4.3.2 Land use type

The land use type also influences pedestrians' perception of safety and satisfaction levels, impacting their crossing behavior. Pedestrians perceived lower safety and satisfaction levels at religious places and commercial areas. This could be due to a lack of pedestrian-friendly infrastructure, the presence of parked vehicles, and high vehicular speed at those locations. Alternatively, pedestrians perceive higher safety and satisfaction near educational areas. In Patiala city, traffic signals with separate pedestrian phases commonly exist in educational areas, which reduces the pedestrian crossing difficulty; consequently, pedestrians perceive a higher level of comfort in these locations. Effati and Saheli [51] investigated the influence of rural land uses and accessibility-related factors on pedestrian safety in Guilan province, Iran, utilizing GIS and machine learning techniques. The study revealed that residential land uses had the most adverse effect on safety. Additionally, it confirmed that commercial and retail, governmental, and institutional land uses, along with the number of access roads, negatively impacted pedestrian safety on rural multilane roads. Similarly, Osama and Sayed [52] highlighted those commercial hubs and residential areas with more access points negatively affected pedestrian safety in Vancouver city, Canada. A recent study by Sung et al. [53] demonstrated that pedestrians face a higher risk of being involved in crashes in areas with mixed land use in Seoul, Korea.

4.3.3 Traffic exposure

The present study finding shows a positive correlation between higher speed and a lower level of safety and satisfaction. The former studies also reported similar observations. For example, a study conducted by Gårder [54] in the USA concluded that wide roadways and faster speeds increase the number of pedestrian deaths. Alhajyaseen et al. [55] also acknowledged that speed is a major factor in pedestrian vehicular crashes in Japan. The earlier research in Indian metropolises also drew similar conclusions [1, 14-16]. Furthermore, studies have confirmed the effects of traffic exposure on child pedestrian safety in the context of HICs [56-58].

4.3.4 Pedestrian-vehicular interaction

The model's output reveals a strong negative correlation between the average TTC and pedestrians' perceptions of safety. Due to the lack of pedestrian crossing facilities, wider roads, and faster-moving vehicles, the average TTC value is much lower in religious and commercial areas. On the other hand, the average TTC is significantly higher and close to an educational hub. This may be because educational hubs have traffic signals with dedicated pedestrian phases and user-friendly crossing facilities. Several earlier studies have assessed pedestrian safety utilizing TTC and also identified a significant and negative association between pedestrian-vehicular collisions and lower TTC values in the context of both LMICs and HICs [59-63].

4.3.5 Sociodemographic characteristics

The model result indicates that females perceived lower safety compared to male pedestrians. Pedestrians with a lower educational qualification also perceived a higher risk and lower satisfaction level compared to pedestrians with a higher education level. Zhang et al. [64] acknowledged that pedestrian crossing behavior and risk perception improve with their education levels. Lartey [65] also revealed that pedestrians with lower educational backgrounds were unable to accurately predict the risk of pedestrian crashes and injuries. Duperrex et al. [66] emphasized the importance of traffic safety education to promote safe crossing behavior among pedestrians. A recent study by Mukherjee and Mitra [8] confirmed that the risk associated with signal violations by pedestrians with lower educational backgrounds is significantly higher in urban settings in India.

Pedestrians' trip purpose plays a significant role in pedestrian risk perception. Pedestrians committing religious and entertainment-related trips have a higher risk perception than educational or office-related trips. A few past studies have confirmed the impact of pedestrian trip characteristics, such as going to work or coming back from work, within the framework of HICs [67, 68]; however, none of the prior studies have demonstrated the effect of various trip purposes on pedestrian risk perception.

4.3.6 Intended mode of transportation

The intended mode of transportation for pedestrians also influences their perceived satisfaction. For example, a pedestrian waiting for a bus may experience lower satisfaction levels. This could be attributed to the lack of real-time bus service information, inadequate designated bus stop facilities, and the absence of suitable access to bus stops in mid-sized Indian cities, leading to increased unease among pedestrians. This finding underscores the broader implications of urban planning and strategic decisions on pedestrians' satisfaction levels and risky crossing behavior. The study completed by Mukherjee and Mitra [8] also discovered that pedestrian red-light jumping behavior is significantly more prevalent near bus stops in Indian metropolitans. Cheranchery et al. [69] acknowledged that the absence of pedestrian infrastructure is primarily responsible for the heightened risk perception by pedestrians near a bus stop.

## 5. RECOMMENDATIONS FOR COUNTERMEASURES AND POLICY INTERVENTIONS

To lower the risk of pedestrian crashes and to promote pedestrian safety and convenience, it is crucial to develop suitable action plans that have been proven to reduce pedestrian fatalities and injuries [70-77]. The following corrective actions and policy interventions are suggested in light of several essential inferences from the present study (Table 7).

**Table 7.** Recommendations of countermeasures to improve pedestrian safety and satisfaction

| Characteristics | Risk Factors | Recommendations |
|---|---|---|
| Roadway Factors | Absence of Pedestrian Phase | • The provision of a dedicated pedestrian signal with sufficient pedestrian phase is recommended in commercial zones and religious places [8]. |
| | Carriageway Width | • Construction of a pedestrian refuge island with a separate pedestrian phase is suggested [12].<br>• Pedestrian movement can be controlled with the help of traffic police in the nonappearance of a traffic signal. |
| | Zebra Crossing | • A pedestrian zebra crossing is essential near commercial areas, religious places, bus stops, etc. [1].<br>• Pedestrian crossing signs also need to be provided near zebra crossings. |
| | Absence of Adequate wide Sidewalk | • Adequate wide, encroachment-free sidewalk facilities must be provided for pedestrians.<br>• To control pedestrians' unsafe movements, pedestrian guard rails must be provided along with designated openings [16]. |
| | Lack of Pavement Marking | • Adequate pavement markings such as lane markings, edge and stop lines, and zebra crossings must be provided [16].<br>• Appropriate speed limit marking, 'bus lane,' 'pedestrian zone,' etc. markings on the pavement are also suggested [16]. |

| | | |
|---|---|---|
| | On-Street Parking | • The present study recommends suitable on-street/off-street parking arrangements near commercial sectors [70].<br>• On-street parking for vehicles must be strictly forbidden and enforced near intersections. |
| | Curve at intersection | • Appropriate traffic calming measures at the approach of an intersection (at a minor road) are suggested [16].<br>• Appropriate road signage must be provided, such as pedestrian crossings, curves ahead, speed limits, etc. |
| Pedestrian-Vehicular Interaction | Lowe value of average Time to Collision | • To promote unsignalized intersections, signalization with a dedicated pedestrian signal phase should be available [16].<br>• Encouraging signalized intersections without a clear pedestrian phase is important by implementing a separate pedestrian signal phase that meets pedestrian demand.<br>• At wider crossings, a pedestrian refuge is needed [16]. |
| Land Use Pattern | Religious and Commercial areas | • Pedestrian crosswalks, adequate wide sidewalks, speed limit signs, and adequate illumination are necessary for these areas [1].<br>• Installation of CCTV cameras and speed monitoring in those areas are also vital.<br>• A dedicated pedestrian phase is additionally recommended near that zone.<br>• Controlling pedestrian movement with the assistance of traffic police could be a viable option in the absence of traffic signals.<br>• Road safety campaigns, education, information broadcasting, etc., are additionally important [11]. |
| Traffic Exposures | Higher vehicular speed | • Appropriate traffic claiming measures and electronic speed enforcement, such as speed cameras, vehicle-actuated speed displays, violation deterrent devices, etc., should be installed where pedestrians' movements are significantly high [71].<br>• Installation of appropriate road signage, such as speed limit signs, no overtaking signs, bus stops, pedestrian crossing signs, etc., is also essential [75].<br>• A speed limit making on the pavement may be provided to alert a vehicle driver [8]. |
| Educational Background | Poor educational background (up to primary level) | • Campaigns emphasizing pedestrian safety, educating the public, broadcasting relevant information, etc., are significant for pedestrians from low-income communities [1, 76-77 ]. |
| Trip Purpose | Religious | • Construction of adequate wide sidewalks and crossing facilities in religious areas is necessary.<br>• Controlling vehicular speed near religious places with appropriate traffic calming measures is necessary.<br>• Close to a pedestrian attraction zone, adequate street lighting, road markings, signage, and speed control measures must be installed [76].<br>• At a pedestrian attraction zone, a designated bus stop facility might be constructed [76].<br>• Pedestrian crossing signs and zebra crossing are a must near such areas.<br>• A dedicated pedestrian signal at an attraction zone (religious places) is additionally recommended if pedestrian-vehicle interaction is significantly greater [8]. |
| Mode of Transportation | Bus | • A bus stop with commuter facilities must be provided.<br>• Adequate street lights, zebra crossings, sidewalks, and pavement markings should be constructed close to a bus stop [75].<br>• At a designated bus stop, a bus stops ahead sign or other informatory sign is necessary.<br>• A dedicated bus lane or bus priority lane is also recommended.<br>• Bus stations should be conveniently located near zebra crossings and sidewalks.<br>• Assignment of police personnel near a bus stop could be a feasible option to control pedestrian and vehicle movements [14]. |

The study recommends several measures to enhance pedestrian safety and satisfaction levels. Firstly, it suggests the implementation of wider and more accessible zebra crossing along with adequate wide footpath facilities close to the intersection. The footpath and zebra crossing must be well connected to confirm pedestrians' comfort and safety. Additionally, installing appropriate traffic calming treatments and ensuring proper pavement markings, including zebra crossings, stop lines, and edge lines, are essential steps to promote pedestrian safety. Off-street parking facilities should be provided in urban areas to mitigate congestion and improve pedestrian accessibility.

To further enhance pedestrian safety, locations with lower Time to Collision (TTC) values should be upgraded with signalization featuring dedicated pedestrian signal phases. Commercial and religious areas require pedestrian crosswalks, wider sidewalk facilities, speed limit signs, and adequate illumination to ensure pedestrian comfort, convenience, and safety. Installing CCTV cameras and implementing speed monitoring in these areas are also crucial measures.

Moreover, urban bus stops should be equipped with commuter facilities and accompanied by adequate street lights, zebra crossings, sidewalks, and pavement markings. In addition, informative signage, such as "bus stop ahead" signs, should be placed at designated bus stops to alert pedestrians and motorists.

Lastly, campaigns aimed at promoting pedestrian safety, educating the public, and disseminating relevant information are essential, particularly for pedestrians from low-educational communities. These campaigns play a vital role in raising awareness and fostering a culture of pedestrian safety among the general populace.

## 6. CONCLUSIONS

Pedestrian safety is a significant concern in LMICs. However, the scarcity of research on pedestrian safety evaluation using crash data can be attributed to the poor and inconsistent collection of such data, a common issue observed in LMICs. Further, in medium-sized Indian cities, the lack of reliable and consistent crash information is a considerable challenge. The current paper examines the critical elements affecting pedestrian perceptions of safety and satisfaction in a medium-sized Indian city with mixed traffic conditions. The critical contributions of the present study are emphasized below.

- The study reveals that religious areas exhibited the lowest pedestrian perception of safety, followed by commercial hubs. The findings indicate that key factors influencing pedestrian safety in these areas include inadequate infrastructure, such as the absence of traffic signals (for both traffic and pedestrians), zebra crossings, wide sidewalks, designated bus stops nearby, and clear sight distance at intersections.
- Pedestrians perceive a higher risk when crossing wider carriageways and report lower satisfaction levels. The current finding underscores the importance of implementing grade-separated pedestrian crossing facilities for wider intersections. Additionally, pedestrian signalization and the inclusion of pedestrian refuge islands may be warranted for wider unsignalized intersections with high pedestrian and traffic volumes to enhance safety and mitigate conflicts between pedestrians and vehicles.
- The Time-to-Collision (TTC), a metric measuring pedestrian-vehicle interaction, was also found to have a strong and negative correlation with pedestrian perceptions of safety. The current research suggests that higher TTC values indicate a reduced frequency of critical interactions between pedestrians and vehicles, thereby lowering the risk of collisions. Therefore, signalization with a designated pedestrian phase is recommended to enhance safety at the crossings with low TTC values. Also, grade-separated pedestrian crossing facilities such as pedestrian underpasses or foot-over bridges may be constructed at intersections with lower TTC values to separate pedestrians from motorized traffic completely.
- It was also revealed that pedestrians typically judge a lower safety level at an intersection having high-speed vehicles. Therefore, it is imperative to enforce speed laws and implement necessary measures to reduce traffic speed in mid-sized Indian cities, particularly at at-grade crossings.
- The model findings suggest that pedestrians with lower educational backgrounds perceive a higher crossing risk at urban intersections in India. Hence, it is essential to enhance pedestrian safety and confidence levels through systematic training and education programs, which are currently lacking in mid-sized Indian cities.
- The current article also emphasizes the impact of sociodemographic factors on pedestrian safety perception and satisfaction levels. It was found that perceived safety and satisfaction levels are lower for pedestrians making religious trips. While the current research underscores the necessity for appropriate and secure pedestrian infrastructure near religious locations, it also suggests that these areas could benefit from systematic road safety education and advocacy to enhance pedestrian safety and crossing activities.
- Lastly, it was acknowledged that the perceived level of pedestrian satisfaction for public bus users is much lower; therefore, locations with more bus routes should be given priority to building safe crossing facilities. In mid-sized Indian cities like Patiala, a significant problem is caused by the absence of a designated bus stop. The dissatisfaction of pedestrians in a mid-sized Indian city can be attributed, in part, to the inaccessibility of the bus stop, the absence of a zebra crossing close to a bus stop, the absence of informative signage, the lack of a dedicated bus lane, and the absence of real-time information on the availability of bus services. To make walking a more comfortable and confident experience for pedestrians, it is essential to provide infrastructure for public bus services that are both safer and more pedestrian-friendly.

Like other studies, this one also has several limitations. Firstly, the perceived safety and satisfaction levels of pedestrians were not correlated with actual crash data due to the unavailability of recent crash statistics. Additionally, this study did not account for the influence of risky driving attitudes on pedestrian risk perception. While the established models in the current paper provide acceptable estimates, a larger sample size for the questionnaire survey would have allowed for a more robust assessment of variables with a greater confidence level. Moreover, the examination of pedestrian-vehicular conflicts was limited to a sample period of six hours, which may not capture all variations and warrants further investigation over a longer duration. Lastly, the study was restricted to only six intersections, which may limit the generalizability of the findings. Expanding the number of intersections would allow for a more comprehensive analysis and enhance the overall robustness of the study.

Future research endeavors could concentrate on establishing a robust relationship between pedestrian risk perception and actual crash occurrences within the framework of Indian mid-sized cities. Enhancing the sample size, encompassing both the number of intersections and survey respondents, is imperative to bolster the reliability and generalizability of findings. Moreover, it is essential to assess the geographical applicability of the proposed models along with conducting model validation. The examination of pedestrian-vehicular conflicts was limited to a six-hour sample period in the current study, necessitating data collection over a more extended duration to capture a broader spectrum of variations. Furthermore, upgrading data collection and extraction techniques would enable advanced analysis in future studies.

Despite several further research possibilities, the present study findings could be valuable in improving pedestrian safety, comfort, and confidence levels at the intersection level in mid-sized Indian cities and similar cities in other LMICs.

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