

Micro-Level Analysis of Pedestrian Movement and Safety: A Case Study of Four Major Intersections in Metropolitan City

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DOI: 10.5281/zenodo.19238984

ABSTRACT

This Pedestrian infrastructure in major urban activity zones of Pune inadequately ensures safety, accessibility, and comfortable walking conditions. Existing facilities often lack systematic evaluation in terms of Pedestrian Level of Service (LOS), compliance with national design standards, and user safety perception, resulting in increased pedestrian vulnerability and reduced walkability. Moreover, most earlier studies are confined to single locations, limiting their applicability across diverse urban contexts. Critical aspects such as age-based pedestrian vulnerability, the influence of intersection geometry on pedestrian safety, and the relationship between surrogate safety indicators like Post Encroachment Time (PET) and crash likelihood remain insufficiently explored, primarily due to the lack of reliable crash data.

To address these gaps, a structured multi-stage methodology was adopted. Representative study sites were selected from commercial, educational, and residential zones to capture heterogeneous pedestrian movement characteristics. Field data collection involved videographic surveys, on-site observations, and structured questionnaire surveys to assess pedestrian perception, comfort, and risk awareness. The collected data were analyzed to identify infrastructure deficiencies, high-risk locations, and pedestrian-vehicle conflict conditions. A detailed compliance assessment was carried out with respect to IRC pedestrian guidelines and Smart City Urban Street Design Guidelines. Based on the findings, evidence-based countermeasures and context-sensitive design strategies were developed.

The study provides a comprehensive compliance evaluation, identification of compliant and non-compliant pedestrian infrastructure segments, and LOS categorization using IRC 103:2012 and the Indo Highway Capacity Manual (2017). The outcomes generate measurable indicators of infrastructure performance, walking comfort, and safety. Overall, the study contributes to a deeper understanding of pedestrian safety challenges in metropolitan environments and offers actionable recommendations to enhance walkability, support inclusive urban transport planning, and assist policymakers and city authorities in prioritizing pedestrian-focused interventions.

Keywords : - Pedestrian Infrastructure; Pedestrian Level of Service; Urban Safety; Post Encroachment Time; Walkability

1. INTRODUCTION

Walking is the most fundamental mode of transportation and a cornerstone of sustainable urban mobility. In rapidly urbanizing metropolitan areas, it forms the essential base layer for daily travel, providing critical access to education, employment, and commerce. As the most environmentally benign transport mode, walking produces zero emissions and promotes public health by reducing lifestyle-related diseases. Furthermore, it serves as the vital "first- and-last-mile" link; the effectiveness of public transit systems like the metro or bus rail depends heavily on the quality of the pedestrian infrastructure leading to them.

Despite these benefits, pedestrian needs are often neglected in urban planning, particularly in developing nations. Pedestrians are classified as **Vulnerable Road Users (VRUs)** because they lack physical protection against motorized traffic. In many cities, the competition for road space is heavily skewed toward high-speed vehicles. Sidewalks are frequently compromised by encroachments, parking, or poor maintenance, forcing pedestrians into the carriageway and increasing the risk of severe injury or fatality.

A review of current literature highlights several critical research gaps:

- **Scale of Analysis:** Most studies focus on isolated corridors, failing to capture the spatial variability of a whole metropolitan area.
- **Demographic Sensitivity:** There is a lack of focus on how vulnerability differs across age groups, such as

children and the elderly.

- **Geometric Comparisons:** Systematic comparisons between different intersection types (signalized vs. unsignalized) are rare.
- **Framework Validation:** Many safety indicators lack the cross-site validation necessary for broad policy application.

This study addresses these gaps by assessing pedestrian infrastructure and safety across four high-density nodes in Pune: **Bhumkar Chowk, Bhujbal Chowk, Laxmi Chowk, and Wakad Chowk**. These intersections are vital transit points for the Hinjawadi IT Park and surrounding residential zones, yet they suffer from systemic deficiencies. Issues range from the complete absence of formal crossings at Bhumkar Chowk and severe surface deterioration near Bhujbal Chowk, to vendor encroachments and non-functional signals at Laxmi and Wakad Chowks.

By conducting a multi-location, demographic-sensitive analysis of these specific sites, this research aims to provide evidence-based recommendations. The goal is to transform these chaotic environments into inclusive, safe, and resilient urban spaces that prioritize the most vulnerable road users.

2. LITERATURE REVIEW

Zegeer et al. (2001) conducted one of the earliest comprehensive studies on pedestrian crash characteristics in urban areas using crash data from over 2,000 locations across the United States. The authors applied regression-based models to relate pedestrian crash frequency with roadway and traffic characteristics such as number of lanes, presence of medians, and marked crosswalks. Their findings indicated that multilane roads and higher vehicle speeds significantly increase pedestrian crash risk. However, the study relied solely on historical crash data and did not consider pedestrian behavioral aspects or near-miss events, limiting its proactive safety assessment capability.

Lyon and Persaud (2002) analyzed pedestrian crashes at signalized and unsignalized intersections in Toronto, Canada, using eleven years of crash data. The authors emphasized the role of turning traffic volumes, particularly left-turn movements, in influencing pedestrian crash occurrence. Their negative binomial regression models showed that turning volumes were more critical predictors than total traffic volume at three-leg intersections. Although the study provided valuable insights into operational factors affecting pedestrian safety, it did not explicitly incorporate pedestrian exposure characteristics such as waiting time or compliance behavior.

Torbic et al. (2010) developed a pedestrian safety prediction methodology specifically for urban signalized intersections as part of the Highway Safety Manual (HSM). Using crash data from urban and suburban arterials, the authors proposed base predictive models for three-leg and four-leg signalized intersections and introduced accident modification factors (AMFs) to account for site-specific characteristics. The study demonstrated that pedestrian volume, traffic volume, number of lanes, and crossing width significantly influence pedestrian crash frequency. A major contribution of this work lies in its attempt to quantify the effects of infrastructure-related variables on pedestrian safety. However, the applicability of the model is constrained in developing countries due to differences in traffic composition and pedestrian behavior.

Landis et al. (2001) examined the relationship between pedestrian level of service (PLOS) and roadway geometric characteristics using field observations and user perception surveys. The study incorporated variables such as sidewalk width, lateral separation from traffic, traffic volume, and vehicle speed. The authors concluded that inadequate sidewalk width and lack of buffer space significantly reduce pedestrian comfort and perceived safety. While the study focused primarily on comfort rather than crash outcomes, it established a strong link between infrastructure quality and pedestrian behavior, which is indirectly related to safety.

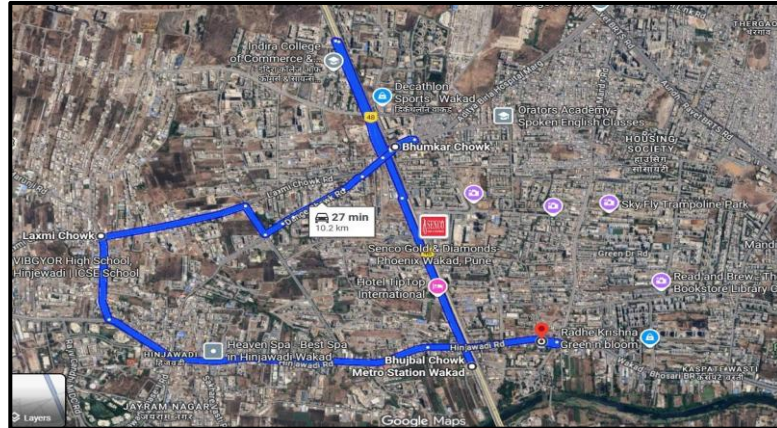
Kadali and Vedagiri (2013) analyzed pedestrian gap acceptance behavior at uncontrolled midblock crossings under mixed traffic conditions in India. Using videographic data, the authors studied pedestrian waiting time, accepted gaps, and crossing speed. Their results showed that pedestrians in Indian cities accept significantly shorter gaps compared to pedestrians in homogeneous traffic environments, leading to increased conflict potential. The study highlighted the importance of considering local traffic behavior while assessing pedestrian safety. However, it did not quantify conflicts using surrogate safety indicators such as PET or TTC.

Rao et al. (2016) investigated pedestrian crossing behavior at signalized intersections in Indian metropolitan cities using video-based data extraction. The study analyzed pedestrian compliance with signals, crossing speed, and delay. The authors found that longer pedestrian delays increase signal violations and risky crossing behavior. Although behavioral insights were robust, the study lacked direct linkage with crash or conflict-based safety indicators.

3. STUDY AREA

The study area comprises four major signalized intersections in the rapidly urbanizing western corridor of Pune, namely Bhumkar Chowk, Bhujbal Chowk, Wakad Chowk, and Kala Khadak Chowk. These locations were selected due to their strategic importance and high pedestrian activity arising from a dense mix of residential neighborhoods, educational institutions, and commercial hubs in their immediate surroundings. Land-use

The study focuses on: (i) assessing the existing physical condition and continuity of the pedestrian network, (ii) evaluating the accessibility and usability of current pedestrian infrastructure for vulnerable user groups, including older adults, children, and persons with disabilities, and (iii) determining the Pedestrian Level of Service (LOS) of the existing facilities in accordance with the guidelines prescribed in IRC:103-2012.



4.FIELD DATA COLLECTION

Table 1.0 : Study Site Geometry & Traffic Characteristics

Sr No	Name of Intersection	No of approach	Turning Movement of Vehicles	Crosswalk Dimension	Pedestrian Volume (Ped/h)	Pedestrian green interval (Sec)
1	Bhumkar Chowk	4	LT	12.5m×2.0 m	550	40
2	Bhujbal chowk	4	LT	10.0m×1.8 m	380	38
3	wakad chowk	4	LT	10.0m×3.30 m	150	37
4	kala khadak chowk	3	LT	5.0m×7.0 m	52	35

A questionnaire survey was conducted at the study locations to assess pedestrians' perceived risk, their views on the importance of road safety, knowledge of traffic rules and regulations, as well as any prior experience with road crashes. The survey also gathered information on pedestrians' sociodemographic characteristics to provide a more comprehensive analysis. The survey was conducted over six hours at each site, from 8 to 11 am and 5 pm to 8 pm, with a minimum of 100 responses collected at each location. To ensure respondents could easily understand the questions, the questionnaire was provided in English, as well as regional languages (Hindi and Punjabi) (Fig. 4: sample questionnaire). Participants were selected based on their willingness to participate, and their responses were recorded immediately after they crossed the intersection.

Gender: Male /Female
 Age: Less than 18 /18 to 29 / 30 to 49 / 50 and above
 Educational Qualification: Nil / Primary / Secondary / Graduation / Post Graduation and Above
 Employment Status: Unemployed / Office Worker / Industrial Worker / Business / Student / others
 Trip Purpose: Education / Business / Job / Entertainment and Religious / Shopping / Medical Treatment / Others
 Daily User: Yes / No
 Pedestrian's Intended Mode of Transport Immediately After Crossing: Bus / Paratransit / Own Vehicle / Walking
 Pedestrian Perceived Risk:
 Scale
 Very Low 1 2 3 4 5 6 Very High
 Your Opinion on the Importance of Road Safety:
 Scale
 Least Important 1 2 3 4 5 6 Highly Important
 Knowledge of Traffic Rules and Regulations:
 Scale
 Very Poor 1 2 3 4 5 6 Excellent
 Pedestrian Prior Experience of Road Crashes (self-reported): Yes / No
 The meaning and significance of the following road signage were asked to explain to the survey respondent

Fig 3. Sample Questionnaire Form

4. RISK PERCEPTION

To evaluate the safety dynamics from the perspective of non-motorized road users, a comprehensive questionnaire survey was conducted across four selected signalized intersections. This study specifically targeted the morning peak hours (8:00 AM to 11:00 AM) to capture the sentiments of commuters navigating high-volume traffic conditions. The primary objective of the survey was to assess pedestrian perceived risk and gather qualitative data on their overall views regarding road safety. Furthermore, the instrument measured the participants' foundational knowledge of traffic rules and regulations, providing critical insight into whether risky crossing behaviors stem from a lack of awareness or a conscious response to the existing infrastructure.

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Risk Perception Study: Assessment Parameters

To accurately quantify Pedestrian Perceived Risk at signalized intersections during the morning peak (8:00 AM – 11:00 AM), the study evaluates several key parameters. These are categorized into human factors, traffic operations, and physical infrastructure.

Human and Demographic Factors

These parameters identify how individual characteristics influence the feeling of safety:

Demographic Profile: Age, gender, and physical mobility levels.

Past Experience: History of "near-misses" or witnessing accidents at the specific intersection.

Trip Urgency: The influence of morning commute pressure on the willingness to accept smaller traffic gaps.

Crossing Intent: Whether the pedestrian is crossing for work, transit access, or leisure.

Traffic Operational Parameters

These are the dynamic elements of the intersection that pedestrians encounter in real-time:

Vehicle Speed: The observed speed of approaching vehicles during the pedestrian "Walk" phase.

Conflicting Turning Movements: The frequency of vehicles making left or right turns that intersect with the pedestrian path.

Pedestrian Delay: The total waiting time at the curb; excessive delays often increase perceived risk and lead to illegal crossings.

Traffic Volume: The density of motorized vehicles during the 8:00 AM to 11:00 AM window.

Geometric and Infrastructure Parameters

The physical design of the intersection plays a crucial role in how safe a pedestrian feels:

Crosswalk Length: Total distance a pedestrian is exposed to traffic while crossing.

Presence of Refuge Islands: Availability of a safe median space for pedestrians to wait mid-crossing.

Signal Visibility: The clarity and placement of pedestrian signal heads (Green/Red man).

Condition of Road Markings: The visibility of zebra crossings and stop lines for vehicles.

Behavioral and Cognitive Parameters

This measures the pedestrian's mental state and their knowledge of safety:

Signal Compliance: Willingness to wait for the pedestrian green light versus "gap-seeking" behavior.

Knowledge of Traffic Rules: Understanding of specific signals, such as the meaning of a flashing pedestrian light.

Situational Awareness: Level of distraction (e.g., mobile phone usage) while navigating the intersection.

Perceived Safety Rating: A subjective score (e.g., Likert Scale 1–5) provided by the pedestrian regarding their comfort level at that location.

5.SURVEY OVERVIEW & OBJECTIVE

Goal & Objective : To assess pedestrian's Perceived risk

To check pedestrians view on the importance of road safety

,knowledge of Traffic rules & regulations .

Target Audience : Pedestrians crossing the intersections as well as the pedestrian's in the ost congested places in Pune .

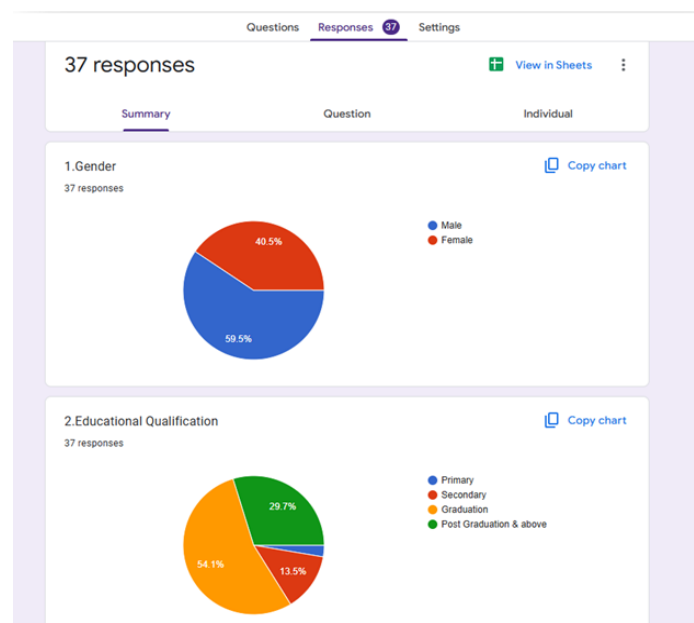
Time Line : Morning Peak Hour (8 – 11 am)

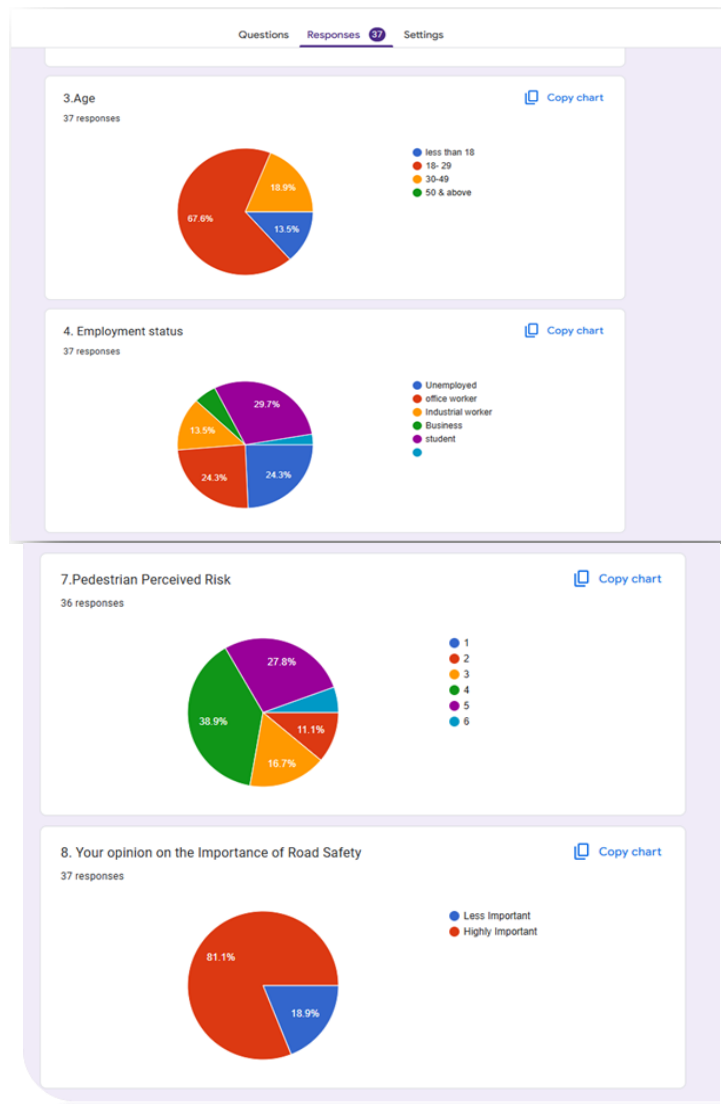
Evening Peak Hour (5 - 8 pm)

Tool Used : Google Form

Total Responses : 40 (Till 25 Nov 2025 -12 am)

6.RESULTS & DISCUSSION





5. CONCLUSIONS

Proposed Mitigation Measures for Enhancing Pedestrian Safety

To counteract the perceived and actual risks identified at the four signalized intersections, several engineering and management strategies are proposed. These measures focus on improving visibility, reducing conflict points, and streamlining traffic flow during peak hours.

Parking Management and Sight-Line Improvements

Improperly parked vehicles near intersections often obstruct the vision of both drivers and pedestrians, leading to high-risk "blind-spot" scenarios.

Provision of Off-Street Parking: To reclaim road space and improve visibility, existing on-street parking should be relocated to dedicated off-street parking lots or multi-level facilities.

Dedicated Parking Lanes: Where on-street parking is unavoidable, it should be restricted to a clearly demarcated dedicated parking lane located well away from the intersection throat to ensure a clear "sight triangle" for turning vehicles.

Infrastructure and Pedestrian Realm Improvements

The physical environment must be designed to accommodate the volume of commuters observed during the 8:00 AM to 11:00 AM peak.

Footpaths with Standardized Width: Sidewalks should be widened to meet peak demand, ensuring a continuous, unobstructed walking surface that prevents pedestrians from spilling over into the motorized carriage-way.

High-Visibility Zebra Crossings: Pedestrian crossings should be marked using thermoplastic retroreflective paint. These markings must be maintained regularly to ensure they remain visible to high-speed approaching traffic.

Strategic Pavement Markings and Signage

Clear communication through road markings reduces confusion and improves driver compliance.

Proper Pavement Markings: This includes the application of "Stop Lines" placed 3 meters ahead of the zebra crossing and "Keep Clear" box markings to prevent vehicles from blocking the pedestrian path during traffic congestion.

Standardized Road Signage: Installation of overhead and side-mounted signs, such as "Pedestrian Crossing Ahead" and "Speed Limit" signs, provides essential cues to motorists to reduce speed before reaching the conflict zone.

Measures to Reduce Jaywalking

Jaywalking is often a response to poor infrastructure or long waiting times. The following measures aim to "channelize" pedestrian movement:

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