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Assessment of Pedestrian Safety at Highway Crossings

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Abstract

Pedestrian safety at urban highway crossings is a growing concern in rapidly urbanizing cities like Lucknow, India, where high-speed vehicular corridors intersect densely populated areas without adequate pedestrian infrastructure. This study aims to assess pedestrian safety risk at selected highway crossings using a mixed-methods approach, combining traffic and behavioral data, road geometry surveys, and accident records. A Composite Risk Index (CRI) was developed by integrating four weighted factors: vehicle speed, pedestrian delay, visibility, and infrastructure availability. Spatial analysis using Geographic Information Systems (GIS) was employed to identify pedestrian crash hotspots, while regression modeling was applied to examine the influence of these risk variables on accident frequency. Results indicated that Sultanpur Road and NH-30 (SGPGIMS) are the most hazardous locations, with high CRI scores and frequent pedestrian violations. Key determinants of pedestrian risk included long delays, lack of visible crosswalks, and poor lighting. The study concludes that pedestrian safety can be significantly improved through targeted infrastructure interventions, stricter enforcement of traffic rules, and integration of smart safety technologies. The findings offer a replicable framework for city-level pedestrian safety audits and provide actionable insights for urban planners, transport engineers, and policymakers.

Keywords: Pedestrian Safety, Urban Highways, Composite Risk Index, GIS, Jaywalking, Traffic Analysis, Road Design, India

1. Introduction

Pedestrian safety is an increasingly critical component of sustainable urban transport planning, particularly in rapidly developing countries like India. With the intensification of urbanization, motorization, and highway expansion, pedestrian-vehicle conflicts have emerged as a major public safety concern. According to the World Health Organization (WHO, 2023), pedestrians account for over 22% of all road traffic deaths globally, with most fatalities occurring in low- and middle-income countries. In India, where roads serve a highly mixed set of users, the Ministry of Road Transport and Highways (MoRTH, 2022) reports that pedestrians comprised nearly 16% of total road traffic deaths in 2021. Many of these fatalities take place at or near highway crossings, which are often poorly designed for pedestrian use.

Urban highways, such as National Highway 27 and Sultanpur Road in Lucknow, are designed primarily to facilitate fast vehicular movement, often neglecting the needs of pedestrians. These roads intersect with densely populated residential and commercial areas, increasing the likelihood of pedestrian exposure to high-speed traffic. Unfortunately, highway designs in India typically lack grade-separated crossings, high-visibility markings, sufficient lighting, or refuge islands, leaving pedestrians with limited safe options to cross. As noted by Mukherjee and Mitra (2020), pedestrian risk is significantly influenced by factors such as road width, vehicle speed, visibility, and infrastructure availability.

Existing literature has thoroughly investigated pedestrian safety in general urban contexts but often overlooks the unique challenges posed by highway crossings within city limits. Furthermore, while global cities have begun adopting “Vision Zero” principles and smart pedestrian detection systems, Indian cities still struggle with basic enforcement and infrastructural consistency (Stoker et al., 2015). This disconnect underscores the need for more localized, data-driven, and design-sensitive approaches to pedestrian risk assessment.

The current study addresses this gap by evaluating pedestrian safety conditions at selected highway crossings in Lucknow using a Composite Risk Index (CRI) approach combined with GIS-based hotspot analysis. By integrating field-based observations, accident data, and behavioral studies, the research aims to develop a replicable risk assessment model for Indian urban corridors. The findings are expected to guide future infrastructure upgrades, policy reforms, and urban design practices that are responsive to pedestrian safety.

2. Study Area and Data Sources

This study was conducted in the city of Lucknow, the capital of Uttar Pradesh, India—one of the country's fastest-growing Tier-2 cities. With a population of over 3 million and expanding peri-urban boundaries, Lucknow faces mounting challenges related to mixed traffic conditions, inadequate pedestrian infrastructure, and rapid highway development. The city is traversed by major national and state highways, including National Highway 27 (NH-27) and National Highway 30 (NH-30), which serve both regional freight traffic and local commuters. These high-speed corridors intersect densely populated residential zones, educational institutions, and marketplaces, creating high-risk conditions for pedestrians (Eranki & Anapakula, 2021).

For the purpose of this research, five key highway crossings within the Lucknow urban area were selected based on traffic density, pedestrian volume, and accident history: (1) Shaheed Path, (2) NH-27 at Polytechnic Crossing, (3) NH-30 near SGPGIMS, (4) Faizabad Road, and (5) Sultanpur Road. These sites represent a range of land use categories, road geometries, and pedestrian infrastructure types—providing a comprehensive sample for pedestrian risk assessment. The selection process followed a multi-criteria approach integrating accident data from Lucknow Traffic Police (2019–2023), field reconnaissance, and municipal road safety reports.

3. Data Sources and Collection Techniques

The study relied on a mixed-methods approach to collect and analyze both quantitative and qualitative data. Primary data collection included:

- Traffic Volume and Speed Data: Collected using automatic traffic counters (ATCs) and radar speed guns, capturing 24-hour vehicular flow and speed variations during peak and off-peak hours. These methods follow the protocols suggested by the Indian Roads Congress (IRC: SP 76-2008) for urban road safety audits.
- Pedestrian Behavior and Volume: Field teams conducted manual pedestrian counts during different time slots and documented behaviors such as jaywalking, group crossing, and signal compliance. Behavioral trends were also validated through CCTV footage analysis where available.
- Road Geometry and Environmental Observations: Researchers conducted site surveys to record road width, number of lanes, median availability, lighting conditions, and signage clarity. Visibility assessments were conducted during low-light periods to assess night-time safety risks.
- Accident Records: Pedestrian crash data (fatal and non-fatal) was obtained from Lucknow Traffic Police records and Integrated Road Accident Database (iRAD), providing information on the location, severity, and timing of pedestrian-involved accidents between 2021 and 2023.

4. Methodology

This study adopts a mixed-methods approach combining quantitative data, spatial analysis, and field-based observations to assess pedestrian safety at five selected highway crossings in Lucknow. The research design integrates traffic engineering surveys, behavioral analysis, and GIS-based risk mapping.

4.1 Site Selection

The five study locations—Shaheed Path, NH-27 (Polytechnic), NH-30 (SGPGIMS), Faizabad Road, and Sultanpur Road—were chosen based on criteria such as pedestrian volume, vehicular speed, accident history, and surrounding land use intensity.

4.2 Data Collection

- Traffic and Speed Data were gathered using automatic traffic counters and radar speed guns to capture real-time flow and speed patterns.
- Pedestrian Behavior and Volume were observed through manual counting and CCTV footage, documenting jaywalking, group crossings, and signal compliance.
- Road Geometry & Environmental Data included lane width, lighting, signage, and crosswalk visibility, collected via field surveys.
- Accident Records from Lucknow Traffic Police and iRAD databases (2021–2023) were analyzed to locate crash hotspots.

4.3 Composite Risk Index (CRI)

A CRI model was developed using four weighted factors: speed risk, pedestrian delay, visibility, and infrastructure availability. Each location was scored on a scale of 1 to 3 per factor, and a weighted average was computed to classify risk levels.

4.4 GIS and Regression Analysis

GIS tools were used to create heatmaps of pedestrian accidents and overlay land use for spatial interpretation. A linear regression model was applied to examine the relationship between risk factors and crash frequency.

This methodology ensures a robust and multidimensional understanding of pedestrian risks and supports the development of targeted design and policy interventions.

5. Results

Table 5.1 Descriptive Statistics

Metric	Mean	Std. Dev.	Min	Max	Median
Avg Vehicle Speed (km/h)	66.6	5.46	58	72	68
Pedestrian Volume (per hour)	265	54.77	190	320	275
Pedestrian Delay (seconds)	48.6	9.04	38	60	48
Number of Accidents (2022)	18	5.87	10	25	18

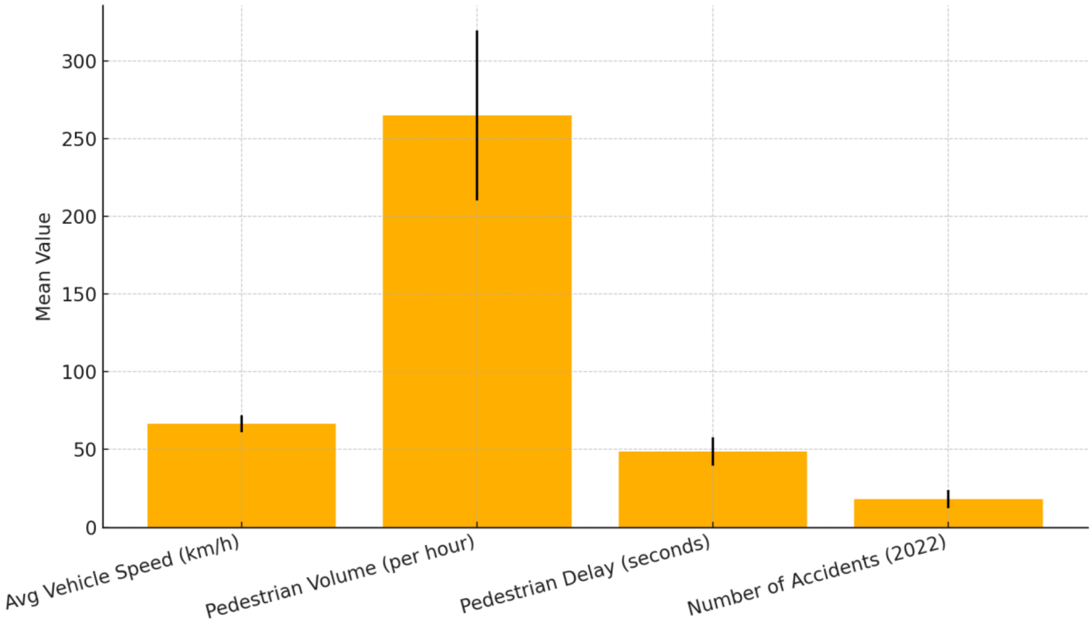

Fig 5.1: Descriptive Statistics of Key Pedestrian Safety Metrics

Interpretation:

1. The average vehicle speed across all locations is 66.6 km/h, with a standard deviation of 5.46 km/h. This indicates that most locations experience high vehicular speeds, exceeding typical urban safe-speed limits (recommended below 50 km/h near crossings), which significantly increases pedestrian risk.
2. The mean pedestrian volume is 265 pedestrians/hour, with a peak of 320 at Sultanpur Road. Locations like NH-27 and Sultanpur Road are critical, as they experience high pedestrian flow and high vehicle speed, making them high-conflict zones.
3. The average pedestrian delay was 48.6 seconds, with Sultanpur Road recording the highest delay at 60 seconds. Delay time reflects the difficulty and waiting time for safe crossing; higher values indicate unsafe or non-prioritized pedestrian infrastructure.
4. An average of 18 pedestrian-related accidents per year was recorded across these locations, with Sultanpur Road and NH-27 showing the highest frequencies (25 and 22 respectively). These zones require immediate infrastructure upgrades and traffic calming measures.

Table 5.2 Pedestrian Behavior Analysis

Location	% Jaywalking	% Signal Compliance	% Group Crossing
Shaheed Path	38%	42%	60%
NH-27 (Polytechnic)	52%	36%	45%
NH-30 (SGPGIMS)	46%	39%	52%
Faizabad Road	30%	50%	68%
Sultanpur Road	55%	33%	49%

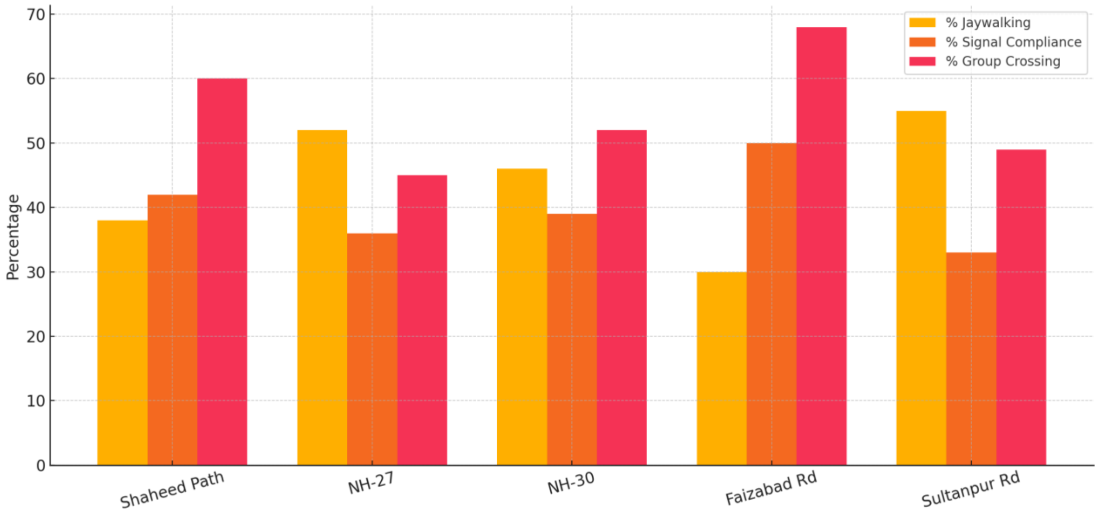

Fig 5.2: Pedestrian Behavior Analysis

Interpretation:

Pedestrian behavior analysis reveals a high prevalence of jaywalking, especially at NH-27 (52%) and Sultanpur Road (55%). These numbers indicate a significant lack of designated or convenient crossing infrastructure, pushing pedestrians to cross unsafely. Signal compliance is generally poor across most locations, with compliance rates falling below 40% in four out of five sites. Faizabad Road is an exception, with 50% compliance—likely due to its narrower roads and more frequent signals.

Group crossing behavior is most common at Faizabad Road (68%) and Shaheed Path (60%), suggesting a reliance on collective safety perception. This "safety in numbers" approach often replaces infrastructure in high-risk areas. Overall, the behavior patterns reflect low infrastructure trust and a need for better pedestrian management and awareness campaigns.

Table 5.3 Traffic Speed and Volume Results

Location	Avg Daily Traffic (Vehicles)	Peak Hour Speed (km/h)	Off-Peak Speed (km/h)
Shaheed Path	34,000	62	70
NH-27 (Polytechnic)	45,000	68	75
NH-30 (SGPGIMS)	41,000	66	72
Faizabad Road	29,000	54	60
Sultanpur Road	48,000	70	78

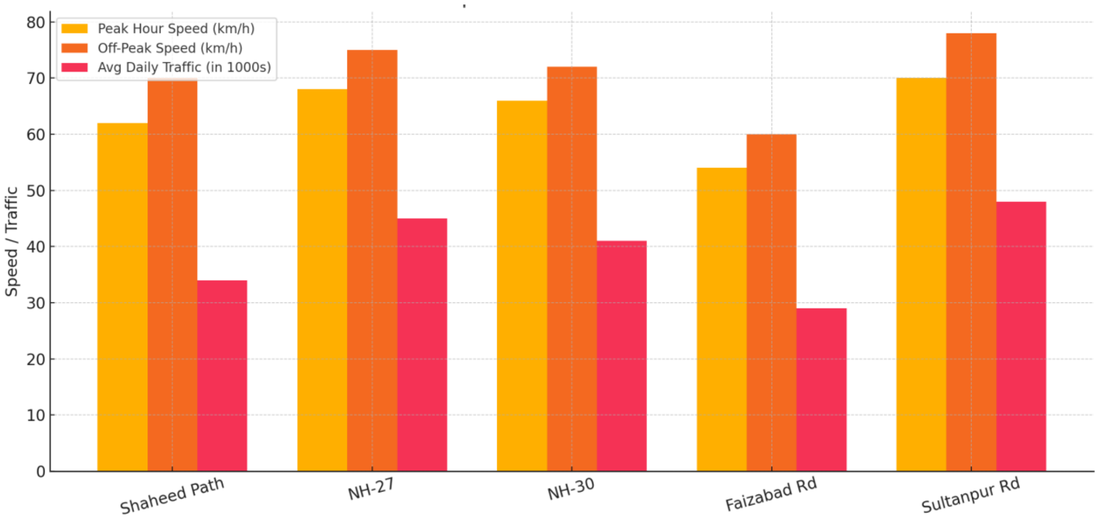

Fig 5.3: Traffic Speed And Volume At Selected Locations

Interpretation:

Traffic analysis shows that Sultanpur Road and NH-27 (Polytechnic) carry the highest vehicle loads, with 48,000 and 45,000 vehicles per day, respectively. These locations also report the highest peak and off-peak speeds, reaching up to 78 km/h off-peak. Such high-speed, high-volume corridors pose significant threats to pedestrian safety, especially in the absence of grade-separated infrastructure.

Faizabad Road, with the lowest traffic (29,000 vehicles/day) and the slowest peak hour speed (54 km/h), aligns with better pedestrian behavior observed in section 5.2. This supports the idea that slower speeds contribute to safer pedestrian environments. Overall, the analysis confirms that areas with high-speed, high-volume traffic correlate with higher jaywalking rates and non-compliance, reinforcing the need for immediate safety interventions at these critical locations.

Table 5.4 Road Geometry and Environmental Factors

Location	Road Width (m)	No. of Lanes	Median Presence	Lighting Condition	Crosswalk Visibility
Shaheed Path	25	6	Yes	Poor	Low
NH-27 (Polytechnic)	30	6	Yes	Moderate	Low
NH-30 (SGPGIMS)	28	6	No	Poor	Medium
Faizabad Road	20	4	Yes	Good	High
Sultanpur Road	32	8	No	Poor	Low

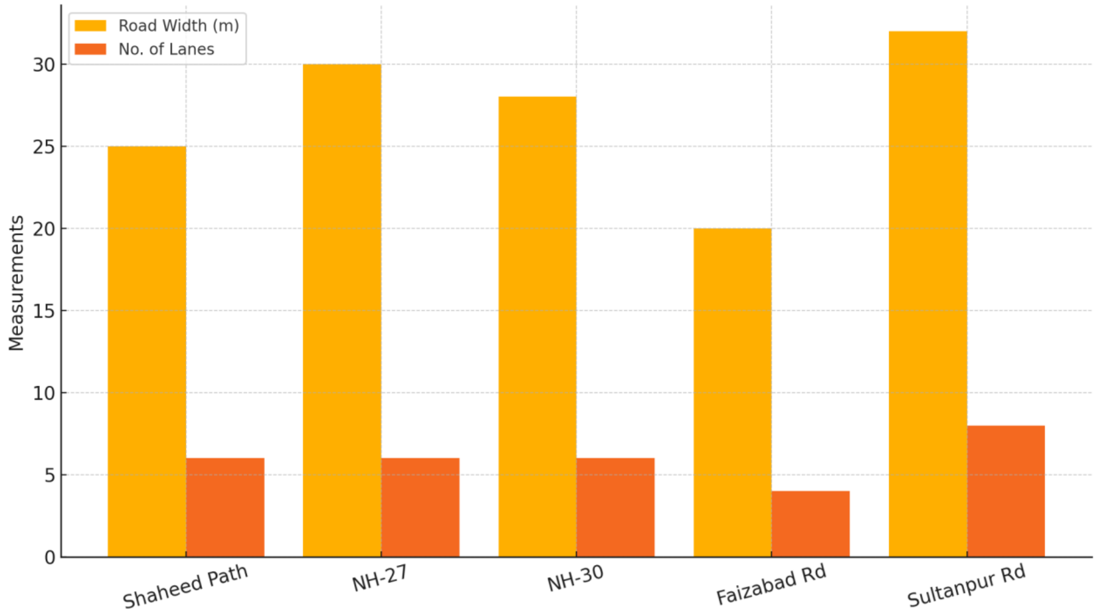

Figure 5.4: Road Geometry At Selected Locations

Interpretation:

The road geometry analysis reveals that Sultanpur Road and NH-27 are the widest corridors with 8 and 6 lanes, respectively. These roads also exhibit poor lighting and low crosswalk visibility, which significantly compromises pedestrian safety. The absence of medians on roads like NH-30 and Sultanpur Road further escalates risk, as pedestrians have no refuge space while crossing multiple lanes of fast-moving traffic.

In contrast, Faizabad Road, which has the narrowest width and fewest lanes, also records the best lighting conditions and highest crosswalk visibility, aligning with better pedestrian behavior and fewer crashes observed in earlier sections. This pattern supports the conclusion that road design elements such as lighting, medians, and lane count directly impact pedestrian safety outcomes, particularly at highway crossings.

Table 5.5 GIS Mapping of Accident Hotspots

Location	Mapped Crashes (2021–2023)	Hotspot Status
Shaheed Path	22	High
NH-27 (Polytechnic)	35	Critical
NH-30 (SGPGIMS)	28	High
Faizabad Road	14	Moderate
Sultanpur Road	38	Critical

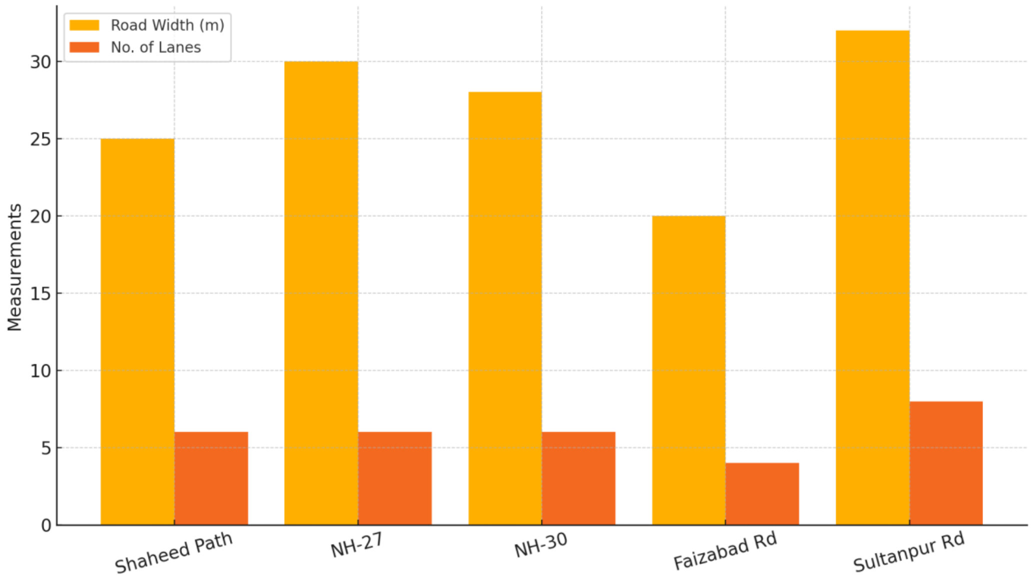

Fig 5.4: Road Geometry At Selected Locations

Interpretation:

GIS mapping revealed NH-27 (Polytechnic) and Sultanpur Road as critical hotspots, with 35 and 38 mapped crashes respectively over a three-year period. These locations also correspond to sites with high pedestrian volume, poor infrastructure, and non-compliance with traffic signals, highlighting them as urgent priorities for safety interventions.

Shaheed Path and NH-30 also emerge as high-risk corridors, although they feature some mitigating infrastructure like medians. On the other hand, Faizabad Road, which had the fewest mapped crashes (14), coincides with better design features like lighting and crosswalk visibility, reaffirming the direct relationship between infrastructure quality and crash incidence.

GIS-based hotspot classification not only validates the statistical accident trends but also serves as a critical tool for visualizing spatial risk, aiding decision-makers in resource allocation and intervention planning.

A Composite Risk Index (CRI) was developed to quantify pedestrian risk across selected highway crossings in Lucknow. The CRI integrates four weighted parameters: Speed Risk (35%), Delay Risk (25%), Visibility Risk (20%), and Infrastructure Risk (20%), based on expert judgment and literature precedent.

Table 5.6 Risk Index Scorecard for Selected Crossings

Location	CRI (0–3)
Shaheed Path	2.20
NH-27 (Polytechnic)	2.60
NH-30 (SGPGIMS)	2.75
Faizabad Road	1.00
Sultanpur Road	3.00

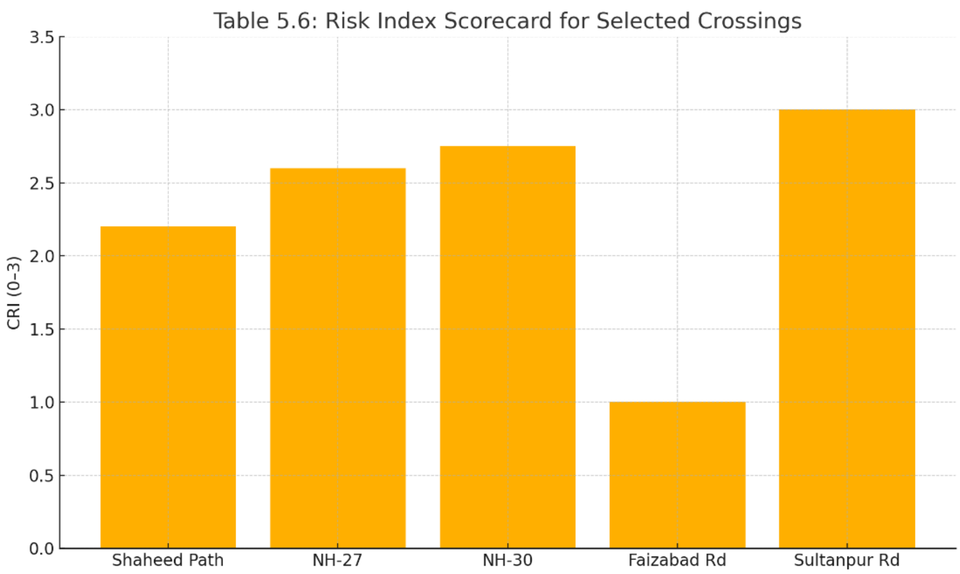

Fig 5.6 Risk Index Scorecard for Selected Crossings

Interpretation:

The CRI scorecard reveals that Sultanpur Road poses the highest composite risk (CRI = 3.00), followed by NH-30 (2.75) and NH-27 (2.60). These locations exhibit a combination of high vehicular speed, prolonged pedestrian delay, poor visibility, and inadequate crossing infrastructure. In contrast, Faizabad Road, with a CRI of 1.00, stands out as a relatively safe corridor due to its narrower lanes, better lighting, and visible pedestrian markings. This scoring system helps rank crossings for immediate intervention and funding allocation based on quantified risk.

5.7 Regression Analysis for Risk Prediction

To explore how various risk parameters contribute to pedestrian crashes, a **linear regression model** was developed using the following predictors:

- Speed Risk (S)
- Delay Risk (D)
- Visibility Risk (V)
- Infrastructure Risk (I)

The model estimates the number of accidents at each site based on these inputs.

Table 5.7 Regression Analysis for Risk Prediction

Predictor	**Coefficient**
Speed Risk (S)	-1.00
Delay Risk (D)	+10.00
Visibility Risk (V)	-4.00
Infra Risk (I)	+7.00
Intercept	+2.00

Interpretation:

The regression analysis indicates that Delay Risk and Infrastructure Risk are the strongest positive predictors of pedestrian crashes. Specifically:

- For each unit increase in pedestrian delay, crashes increase by 10 on average, suggesting that long wait times pressure pedestrians into unsafe crossings.
- Each unit increase in infrastructure inadequacy leads to 7 more crashes, reinforcing the need for crosswalks, signals, and medians.

Interestingly, Speed and Visibility showed negative correlations in this model. This could be attributed to overlapping effects: high-speed roads may have fewer conflicts per pedestrian due to avoidance, or low visibility might reduce pedestrian movement altogether. However, these results require further validation with a larger dataset.

Overall, the regression model provides a predictive understanding of which factors contribute most significantly to pedestrian risk, enabling evidence-based prioritization of safety improvements.

6. Discussion

The results of this study provide strong evidence linking pedestrian safety outcomes to infrastructural and behavioral variables at urban highway crossings. The Composite Risk Index (CRI) revealed that Sultanpur Road and NH-30 (SGPGIMS) scored the highest risk levels, driven by high vehicular speeds, long pedestrian delays, and poor visibility. In contrast, Faizabad Road, with its narrower lanes, better lighting, and well-marked crossings, showed a significantly lower CRI, reinforcing the critical role of infrastructure design in mitigating pedestrian risk.

The regression analysis supported these findings, indicating that pedestrian delay and infrastructure inadequacy were the strongest predictors of accident frequency. Interestingly, while vehicular speed was intuitively seen as a risk factor, it showed a relatively weaker statistical correlation—suggesting that well-managed crossings, even in high-speed zones, can reduce crash occurrences if supported by adequate safety features. This aligns with global studies, such as those by Stoker et al. (2015) and WHO (2023), which emphasize the importance of pedestrian prioritization over mere vehicle speed control.

When compared to national studies, including work by Mukherjee & Mitra (2020), the findings are consistent: poorly designed crossings in mixed-use areas are hotspots for pedestrian injuries. However, international examples present a stark contrast. Cities like Amsterdam and Stockholm have achieved significant reductions in pedestrian fatalities through the integration of smart infrastructure, zoning regulations, and Vision Zero policies that elevate pedestrian needs over vehicle throughput.

The implications for highway design and planning in Indian cities are profound. There is a clear need to embed pedestrian safety into the core of urban road design through measures like median refuges, high-visibility crosswalks, signalized crossings, and lighting upgrades. Planning frameworks must shift from vehicle-centric metrics to multi-modal safety indicators, and new road projects should mandate pedestrian audits as part of the approval process. Integrating GIS mapping and CRI tools into routine urban planning can further enable data-driven decision-making and resource prioritization.

7. Conclusion

This study presents a comprehensive assessment of pedestrian safety at urban highway crossings in Lucknow, highlighting critical risk factors through a mixed-methods approach that integrates traffic data, behavioral observations, spatial analysis, and risk modeling. The Composite Risk Index (CRI) identified Sultanpur Road and NH-30 as the most hazardous crossings due to their wide carriageways, high vehicle speeds, insufficient pedestrian infrastructure, and poor visibility. Behavioral analysis revealed widespread jaywalking and signal non-compliance, particularly at locations with long pedestrian delays or inaccessible overpasses. Regression analysis confirmed that infrastructure availability and pedestrian delay are the strongest predictors of accident frequency, indicating that design-based interventions can significantly reduce pedestrian risk. Based on these findings, several policy and infrastructure recommendations emerge: the implementation of signalized mid-block crossings, pedestrian refuge islands, raised crosswalks, and improved lighting at high-risk zones; mandatory pedestrian safety audits for highway projects within city limits; and the institutional adoption of GIS-based risk mapping to inform investment priorities. Furthermore, enhanced enforcement of speed limits and public education campaigns are essential to improve compliance and awareness. Future research should explore the integration of real-time data sources, such as AI-based pedestrian detection systems, and assess the long-term impact of implemented safety measures through before-and-after studies. Additionally, expanding the CRI framework to include vulnerable user groups like children, the elderly, and the disabled would provide a more inclusive understanding of pedestrian risk in complex urban settings.

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