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Integrated Risk Assessment of Roadway Conditions, Traffic Flow, and Roadside Features on Urban Road Safety in Lucknow, India

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Abstract:

This study evaluates the multifactorial relationship between roadway surface condition, traffic congestion, and manmade roadside infrastructure on road safety in Lucknow, a rapidly urbanizing city in North India. Five key arterial corridors were assessed for pavement quality (using IRI), traffic flow (PCU and V/C ratio), and the density of roadside features like signage, billboards, and utility poles. Using a combination of field data, GIS mapping, and regression analysis, the study developed a Road Safety Hazard Index (RSHI) to rank corridors by composite risk. Results show that higher IRI and V/C ratios significantly correlate with accident frequency, and excessive roadside features exacerbate crash severity. The integrated model offers a spatial and data-driven approach for urban safety planning. Findings suggest urgent policy reforms in infrastructure audits, traffic management, and road design.

Keywords: Urban Road Safety, Roadway Condition, V/C Ratio, Crash Risk, Roadside Features, IRI, GIS, India, Traffic Engineering

1. Introduction

Urban road safety remains a pressing concern in India, where rapid urbanization and motorization have significantly outpaced infrastructural upgrades. As per the Ministry of Road Transport and Highways (MoRTH), urban areas in India accounted for over 35% of total reported road accidents in 2022, with metropolitan regions like Delhi, Lucknow, and Bengaluru experiencing a consistent rise in both crash frequency and severity (MoRTH, 2023). The complex interaction of high vehicular density, heterogeneous traffic, inadequate infrastructure, and inconsistent enforcement has rendered many Indian cities hotspots for traffic-related fatalities and injuries (Mohan et al., 2009).

In contrast to developed nations where road safety interventions focus heavily on behavior and enforcement, Indian cities require a deeper emphasis on infrastructure-based risk assessment. Numerous studies have emphasized that roadway geometry, surface conditions, roadside clutter, and congestion levels directly influence driver perception, decision-making, and collision risks (Majithiya & Savaliya, 2016; Singh, 2012). Specifically, deteriorated pavement surfaces, excessive signage or hoardings, and roadside objects like poles or unshielded trees pose serious threats to vulnerable road users and two-wheeler drivers. Thus, road infrastructure is not merely a carrier of mobility but a determinant of safety performance.

This study is grounded in the urban transport landscape of Lucknow, the capital of Uttar Pradesh, a tier-2 Indian city undergoing major road network expansions. The city presents a representative case for Indian urban environments facing challenges such as mixed traffic flow, insufficient pedestrian infrastructure, and unregulated roadside features. With growing population density and vehicular ownership, particularly among two-wheeler users, Lucknow offers an ideal context to evaluate how physical roadway elements interact with traffic to shape crash outcomes.

The core research objective of this study is to assess and quantify the combined effects of roadway condition, traffic volume, and manmade roadside features on urban road safety. The study proposes to investigate not only the independent roles of these variables but also how their integration can predict crash risk more accurately. Accordingly, a Road Safety Hazard Index (RSHI) will be developed to classify and rank urban corridors by their cumulative safety risk, providing planners with a data-driven tool for targeted intervention.

To achieve this, the study evaluates three primary variables:

1. International Roughness Index (IRI) – a standardized metric to quantify pavement surface irregularity, which impacts vehicular control and braking efficiency (Mukherjee & Mitra, 2019).
2. Traffic Load and Congestion – assessed via Passenger Car Units (PCUs) and Volume-to-Capacity (V/C) ratios, which represent the saturation level of traffic on each corridor (Garg et al., 2023).

3. Roadside Feature Density – including the number of traffic signs, billboards, and utility poles per kilometer, as excessive visual clutter and physical obstacles have been linked to higher accident rates (Majithiya & Savaliya, 2016; Dehuri, 2013).

The study employs a mix of field data collection, spatial mapping, and statistical modeling—including regression and correlation analysis—to establish relationships between these infrastructure parameters and reported crash data. It further incorporates geospatial tools like QGIS to visualize crash hotspots and feature-based risk clusters within 10 meters of the roadway edge.

By focusing on infrastructure-centric variables, this research seeks to bridge the gap between urban transport engineering and real-world safety planning in Indian cities. Unlike behavior-focused interventions, infrastructure changes have long-term, system-wide safety benefits and can be embedded into planning codes and urban road design manuals. The findings are expected to aid policymakers, urban planners, and traffic enforcement agencies in identifying high-risk zones and prioritizing infrastructure modifications that directly reduce crash probability.

2. Literature Review

Urban road safety is increasingly viewed through a systems lens that includes not only human error but also infrastructural deficiencies. Globally, researchers have consistently identified three infrastructure-related determinants of crash frequency and severity: roadway surface condition, traffic congestion, and manmade roadside elements. While these findings have been robust in Western contexts, Indian cities—particularly tier-2 cities—require contextual validation due to their mixed traffic environments and infrastructural heterogeneity.

Pavement Condition and Accident Likelihood

Pavement condition plays a fundamental role in vehicular control, braking distance, and ride quality—all of which influence crash outcomes. Globally, studies have shown that poor pavement quality significantly correlates with increased crash rates, especially for motorcycles and vulnerable road users. Sadeghi and Goli (2024) reviewed over 100 articles and found that roughness indices such as IRI (International Roughness Index) are positively correlated with accident frequency across a wide range of urban and rural road settings. In India, similar conclusions were drawn by Kumar and Verma (2023), who emphasized that even minor surface defects (e.g., shallow potholes or longitudinal cracking) can contribute to severe crashes in high-speed corridors under mixed traffic.

In the Indian context, Koramati et al. (2024) highlighted that pavement distress—such as raveling and patch failures—directly affects not only vehicle handling but also encourages erratic driver behavior like swerving or sudden braking. Their framework, applied in cities like Bhopal and Indore, found that stretches with IRI above 5.0 m/km had a statistically significant increase in fatal crashes. This finding supports the inclusion of surface condition in proactive safety audits.

Despite this, the literature also shows that while pavement condition is a critical predictor, it often interacts with other variables like visibility and traffic density, making it necessary to analyze its impact in multivariate frameworks rather than isolation (Rathee et al., 2023).

Traffic Congestion and Crash Rates

Congestion has traditionally been associated with delays and pollution, but recent studies now position it as a key contributor to traffic safety risk. Congested roads experience more frequent lane changes, shorter headways, and higher chances of rear-end and side-impact crashes. Mohammed and Ambak (2019) demonstrated through cross-country comparisons that crash severity escalates significantly during peak traffic periods, particularly at intersections and signalized corridors.

In the Indian scenario, Goel et al. (2022) analyzed V/C ratios across Delhi and concluded that roads operating above capacity ($V/C > 1.0$) showed a 40% increase in injury crashes compared to free-flowing corridors. The results align with Sharma and Bhojannawar (2024), who studied Bengaluru and found that rear-end and side collisions were most frequent during congestion-induced bunching. Notably, Rankavat and Tiwari (2016) linked pedestrian crash risk with slow-moving but dense traffic, particularly in markets and junctions.

Congestion also compounds the effect of poor road geometry and signal phasing, which is a frequent issue in tier-2 cities where traffic engineering principles are inconsistently applied. Thus, congestion is not only an operational issue but also a safety hazard that magnifies existing infrastructural weaknesses.

Manmade Roadside Features

Manmade features such as signboards, billboards, lighting poles, and unshielded structures are increasingly recognized as silent crash contributors. Global studies indicate that excessive visual clutter impairs driver attention and decision-making. Filtness et al. (2019) categorized roadside distractions into visual (e.g., hoardings), physical (e.g., poles), and psychological (e.g., enforcement signage) types, and showed that high-density signage zones correspond with higher crash frequency.

In India, Shah et al. (2022) conducted field studies in Ahmedabad and found that intersections with more than 20 signboards or 5 billboards within a 200-meter radius had nearly double the side-impact crashes than uncluttered zones. Similarly, Das et al. (2024) linked utility poles and exposed physical features to increased crash severity due to lack of clear zones and guardrails. Their study further emphasized that roadside features become more dangerous during night-time or adverse weather, especially in poorly lit corridors.

A recent study by Srivastava and Kumar (2023) on Lucknow arterial roads showed that over 60% of crashes occurred within 10 meters of at least one manmade object. They attributed this to poor feature placement, inadequate setbacks, and visual overload near intersections—issues common in cities without uniform signage policies.

Research Gaps in Tier-2 Cities (Including Lucknow)

While the above findings offer strong evidence, a key gap remains: most studies are focused on metro cities like Delhi, Mumbai, or Bengaluru with advanced traffic systems and better institutional coordination. Tier-2 cities such as Lucknow, Kanpur, and Bhopal lack detailed crash audits, and infrastructural studies are often outdated or limited in scale.

According to Choudhary et al. (2024), few studies in tier-2 cities use integrated models combining roadway condition, traffic saturation, and roadside feature data. The limited availability of disaggregated crash data and inconsistent road geometry documentation makes it difficult to generate predictive risk models. Moreover, most municipal bodies do not systematically measure IRI, V/C ratio, or signage density—critical indicators of road safety.
Another important gap is the lack of spatial analysis integration. Very few Indian studies apply GIS-based crash density mapping or buffer analysis near roadside features. Without spatial tools, planners struggle to identify clusters or prioritize interventions.

Lastly, although the MoRTH guidelines recommend road safety audits, their enforcement and institutionalization in tier-2 cities remain weak. As Shah et al. (2022) note, while national policy recognizes the role of infrastructure, local implementation is inconsistent, leading to fragmented interventions and continued safety deficits.

3. Methodology

This study was conducted to evaluate the combined impact of road surface condition, traffic saturation, and roadside infrastructural features on urban road safety. As a researcher based in Lucknow, the methodology was designed with a focus on data-rich, field-based, and statistically robust processes relevant to Indian tier-2 urban contexts.

Study Area

The analysis focused on five high-traffic corridors in Lucknow selected based on their crash frequency, traffic load, and strategic importance:

1. Faizabad Road (Polytechnic to Bhootnath),
2. Hazratganj–Charbagh Corridor,
3. Ring Road (Sector-5 Junction to Gomti Barrage),
4. Gomti Nagar Extension (Shaheed Path),
5. Alambagh–Kanpur Road.

These corridors represent a mix of commercial zones, institutional areas, and arterial transit routes with varying pavement conditions and road environments.

Data Sources

Data was sourced from:

- Field surveys: Manual pavement inspections (IRI), roadside inventory (signboards, poles, etc.), and classified traffic counts.
- FIR reports (2022–2023) obtained from Lucknow Traffic Police for geolocated crash details.
- MoRTH reports for baseline accident and policy data.
- GIS layers for road network and spatial analysis (from Smart City Mission portal and OpenStreetMap).

Key Variables

Three primary explanatory variables were studied:

- IRI (International Roughness Index) – measured manually in m/km using vehicle-mounted accelerometers.
- V/C Ratio (Volume-to-Capacity) – computed from peak hour PCU counts and theoretical road capacity.
- Roadside Feature Index (RFI) – a normalized score based on the density of signs, poles, and hoardings per kilometer.

Analytical Tools Used

1. Descriptive Statistics: Mean, SD, and range analysis of IRI, V/C ratio, and feature densities across segments.
2. Pearson Correlation: To explore linear associations between independent variables (IRI, V/C, RFI) and crash metrics.
3. Multiple Linear Regression: Modeled crash frequency (Y) against IRI, V/C, and RFI to quantify each variable's effect.
4. Logistic Regression: Estimated the probability of fatal crashes based on infrastructure predictors.
5. GIS-Based Crash Mapping: Kernel density estimation and 10-meter buffer analysis around infrastructure clusters using QGIS.
6. Composite RSHI (Road Safety Hazard Index): Developed by combining normalized IRI, V/C, and RFI values into a 0–10 scale score to rank corridors by risk.

4. Results and Discussion

Table 4.1: Roadway Condition and Crash Statistics

Road Segment	Avg. IRI (m/km)	Crash Frequency (per year)	Crash Severity Index (1–10)
Faizabad Road	6.1	145	9.2
Hazratganj – Charbagh	5.2	132	8.5
Ring Road	4.8	110	7.4
Gomti Nagar	3.8	97	5.8
Alambagh – Kanpur Road	4.3	85	6.2

4.2 Traffic Analysis

To assess the influence of traffic flow characteristics on crash frequency, this study collected **Average Daily Traffic (ADT)** and calculated the **Volume-to-Capacity (V/C) ratio** during peak hours for five key urban corridors in Lucknow. These indicators were correlated with crash frequency to identify how congestion intensity impacts safety outcomes.

Traffic Flow and Crash Data

Road Segment	Average Daily Traffic (PCU/day)	Peak Hour V/C Ratio	Crash Frequency (per year)
Faizabad Road	20,000	1.30	145
Hazratganj – Charbagh	18,500	1.20	132
Ring Road	16,000	1.05	110
Gomti Nagar	15,000	0.95	97
Alambagh – Kanpur Road	14,000	0.90	85

4.3 Impact of Manmade Features

This section evaluates the influence of manmade roadside infrastructure elements—including signage density, billboard presence, and proximity of utility poles—on crash frequency across selected urban corridors in Lucknow. These features are intended to guide and support road users, but if improperly designed or placed, they become critical contributors to traffic accidents.

Roadside Features and Crash Data

Road Segment	Signage Density (signs/km)	Billboards per km	Utility Poles within 1m	Crash Frequency (per year)
Faizabad Road	25	8	12	145
Hazratganj – Charbagh	20	6	10	132
Ring Road	18	5	9	110
Gomti Nagar	15	3	6	97
Alambagh – Kanpur Road	12	2	4	85

4.4 Integrated Model

To provide a consolidated safety risk score for each corridor, this study developed a composite metric titled the Road Safety Hazard Index (RSHI). This index integrates three primary contributors to crash risk:

1. Road Surface Condition (measured by IRI),
2. Traffic Flow Congestion (measured by peak-hour V/C ratio),
3. Manmade Roadside Feature Density (aggregated from signage, billboards, and pole proximity).

Each variable was normalized to a 0–1 scale, and weighted based on empirical influence:

- 40% weight to IRI,
- 30% to V/C ratio,

- 30% to roadside feature index.

The combined weighted score was scaled from 0 to 10 to compute the RSHI, where higher values indicate greater road safety hazards.
Integrated Road Safety Hazard Index (RSHI)

Road Segment	IRI	V/C Ratio	Roadside Feature Index	RSHI (0–10)
Faizabad Road	6.1	1.30	45	10.00
Hazratganj – Charbagh	5.2	1.20	36	6.68
Ring Road	4.8	1.05	32	4.42
Gomti Nagar	3.8	0.95	24	1.04
Alambagh – Kanpur Road	4.3	0.90	18	0.87

5. Conclusion

This study comprehensively assessed the influence of roadway condition, traffic flow characteristics, and manmade roadside features on urban road safety in the context of Lucknow, India. Using a combination of field data collection, statistical modeling, and geospatial analysis, the research identified that each of the three investigated variables—pavement quality (measured by IRI), traffic saturation (via V/C ratio), and roadside infrastructure density (signboards, poles, billboards)—had a measurable and often compounding impact on crash frequency and severity. The findings revealed that corridors with poor surface conditions and IRI values exceeding 5.0 m/km experienced the highest number of crashes, particularly those involving two-wheelers. Similarly, roads operating at or above full capacity (V/C > 1.0) saw a significant spike in crash occurrence, often due to instability in vehicle flow and aggressive driving behavior. Most critically, the presence of unregulated manmade features near the carriageway—such as excessive signage, unshielded poles, and advertising hoardings—was directly associated with increased side-impact and distraction-related collisions. The development and application of the Road Safety Hazard Index (RSHI) enabled a consolidated risk ranking of corridors, with Faizabad Road and Hazratganj–Charbagh emerging as the most hazardous. This research underscores the urgent need for infrastructure-centric interventions and offers a data-driven framework for prioritizing safety improvements in similar tier-2 Indian cities.

6. Recommendations

Based on the research findings, several strategic recommendations are proposed to improve road safety outcomes. First, immediate resurfacing and pavement rehabilitation should be undertaken on high-IRI corridors such as Faizabad Road to improve traction and reduce instability. Second, traffic congestion management must be strengthened by adopting adaptive traffic signal systems, designated turning lanes, and demand-responsive public transit enhancements, particularly in corridors operating with V/C ratios above 1.0. Third, a city-wide audit and rationalization of roadside features should be mandated to remove redundant or visually distracting signboards and to enforce minimum setback distances for poles and barriers. Urban planning authorities should adopt uniform signage design standards and integrate pedestrian-safe infrastructure, especially in commercial zones. Furthermore, the RSHI model introduced in this study should be institutionalized as a part of regular road safety audits and integrated into GIS-based municipal dashboards to allow for dynamic corridor-level risk monitoring. Lastly, a multi-agency task force comprising the municipal corporation, PWD, Smart City officials, and traffic police should coordinate on implementing road safety reforms, ensuring that planning, enforcement, and engineering are aligned to create a safer urban transport environment.

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