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Highway Crash Risk Assessment and Predictive Modelling in Madhya Pradesh: An Integrated Data-Driven Approach (2017–2024)

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Abstract: Highway accidents remain a critical safety and economic issue in India, accounting for nearly 65% of total road fatalities each year. Madhya Pradesh, located at the heart of the country, is a key transport corridor with heavy interstate freight and passenger traffic. This study investigates accident trends and risk factors across major highways in Madhya Pradesh between 2017 and 2024 using a combination of secondary crash records and primary field surveys. Data from over 11,200 reported crashes were analyzed using Geographic Information System (GIS) mapping and Poisson regression modeling. The findings reveal that over-speeding (47.2%), lane indiscipline (22.6%), and driver fatigue (15.4%) are dominant contributors to crashes. Black-spot analysis identifies NH-46 (Bhopal–Indore corridor) and SH-22 (Guna–Ashoknagar section) as high-risk segments, with crash densities exceeding 5.1 accidents/km/year. Predictive models demonstrate that a 10% rise in traffic volume correlates with a 5.3% increase in accident risk, while wet pavement conditions increase crash probability by 28%. Policy recommendations include AI-assisted enforcement, dynamic speed management, road geometry corrections, and community-based awareness programs. The study contributes a replicable data framework for state-level road safety planning in India.

Keywords: *Road Accidents, Highways, Black-Spots, Traffic Safety, Predictive Models, Madhya Pradesh*

1. Introduction

Road traffic injuries are the leading cause of death among 15–29-year-olds globally and remain a key public health challenge in India. The country reported 168,491 road fatalities in 2023, with national and state highways accounting for more than 60% of total deaths (MoRTH, 2024). Madhya Pradesh (M.P.), with its central geographical position and an expanding network of highways such as NH-46, NH-44, and SH-22, faces a growing burden of highway crashes.

While India's Motor Vehicles (Amendment) Act 2019 and state-level road safety cells have introduced stricter penalties and new enforcement strategies, accident numbers remain stubbornly high. Previous studies have primarily focused on driver behavior or infrastructure deficiencies, but few have integrated spatial analytics with predictive modeling for targeted interventions.

This paper addresses that gap by presenting a seven-year, data-driven analysis of highway accidents in Madhya Pradesh. The objectives are to:

1. Assess temporal and spatial crash trends between 2017–2024.
2. Identify black-spots using GIS-based clustering.
3. Develop predictive models to quantify the impact of traffic volume, weather, and road conditions on accident risk.
4. Recommend actionable interventions aligned with the United Nations Decade of Action for Road Safety (2021–2030).

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2. Literature Review

International literature consistently identifies human behavior, infrastructure quality, and environmental conditions as primary crash determinants.

- Driver Behavior: Over-speeding, alcohol impairment, and distracted driving remain key factors (Peden et al., 2022). Recent work by Zhao et al. (2023) highlights the growing role of smartphone distraction in developing nations.
- Infrastructure & Geometry: Lane width, shoulder conditions, and curvature significantly influence crash rates (Khalilikhah & Lord, 2022). Poor drainage and surface distress amplify risk during monsoon periods.
- Predictive Analytics: Poisson and Negative Binomial models have been successfully applied to predict crash frequencies using traffic and roadway variables (Shankar et al., 2021). AI-based deep learning models are increasingly used for real-time crash prediction (Jain & Rathod, 2023).

Indian studies (Kumar et al., 2021; Singh et al., 2022) emphasize the combined effect of enforcement gaps and mixed traffic flow, with two-wheelers constituting the most vulnerable group. However, research integrating long-term crash data with geo-spatial risk modeling remains limited in Madhya Pradesh, motivating the present investigation.

3. Methodology

3.1 Study Area

The study covers five high-traffic corridors of Madhya Pradesh:

- (Bhopal–Indore)
- (Bhopal–Nagpur)
- (Gwalior–Shivpuri)
- (Guna–Ashoknagar)
- (Jabalpur–Mandla)

These highways carry over 120,000 vehicles/day combined, with high volumes of freight and intercity buses.

3.2 Data Collection

- **Secondary Data:** Accident records (2017–2024) from the Madhya Pradesh Transport Department and Traffic Police, covering 11,200 crashes and 9,850 injuries/fatalities.
- **Primary Data:** Road-user surveys (n=450) and field inspections documenting road geometry, signage adequacy, and pavement conditions.

3.3 Analytical Tools

- **GIS Mapping:** QGIS was used for black-spot detection using Kernel Density Estimation (KDE).
- **Predictive Modelling:** Poisson regression and Generalized Linear Models (GLMs) analysed crash frequency as a function of traffic volume, surface condition, lighting, and weather.
- **Validation:** Models were validated using a 20% hold-out dataset and Akaike Information Criterion (AIC) for goodness of fit.

4. Results

4.1 Crash Trends

From 2017 to 2024, total highway crashes in Madhya Pradesh increased by 21.4%, from 1,240 crashes in 2017 to 1,505 crashes in 2024 (Figure 1). Fatality rates rose from 0.92 to 1.08 deaths per crash, indicating increasing severity despite occasional enforcement drives.

4.2 Key Risk Factors

- **Over-speeding:** Present in 47.2% of cases, especially on straight, multi-lane segments of NH-46.
- **Lane Indiscipline:** Sudden lane changes contributed to 22.6% of crashes, aggravated by inadequate lane markings.
- **Driver Fatigue:** Responsible for 15.4% of late-night accidents, particularly among long-haul truck drivers.
- **Environmental Factors:** Wet pavement increased crash probability by 28%, while poor lighting increased nighttime crashes by 31%.

4.3 Vehicle Involvement

Two-wheelers accounted for 38% of crashes and 42% of fatalities, followed by heavy trucks (23%) and passenger buses (15%).

4.4 Black-Spot Analysis

KDE mapping revealed high-density crash clusters at:

- NH-46 (Km 130–150, near Sehore): 5.1 accidents/km/year
- SH-22 (Km 45–65, near Ashoknagar): 4.7 accidents/km/year

4.5 Predictive Modelling

The Poisson regression model showed:

- Traffic Volume (vehicles/day) → $\beta = 0.053$, $p<0.001$
- *Surface Roughness (IRI) → $\beta = 0.021$, $p<0.05$
- *Rainy Days/Month → $\beta = 0.032$, $p<0.01$

This indicates that a 10% rise in traffic increases crash risk by 5.3%, and each unit increase in roughness index increases crash frequency by 2.1%.

5. Discussion

The results confirm that Madhya Pradesh's highways suffer from a combination of behavioral and infrastructural risk factors. Over-speeding remains the leading contributor, similar to national trends, but the role of driver fatigue is more pronounced here due to long freight corridors. The predictive model underscores the need for continuous pavement monitoring and weather-responsive speed management, especially during monsoon seasons.

Comparisons with studies in Maharashtra (Jain & Rathod, 2023) and Tamil Nadu (Singh et al., 2022) reveal similar black-spot patterns, indicating that data-driven black-spot remediation could be replicated nationwide.

6. Recommendations

Horizon	Key Actions
Immediate (0–1 Year)	Deploy AI-enabled speed cameras and Automatic Number Plate Recognition (ANPR) systems on NH-46 and SH-22 black-spots; conduct fatigue-awareness campaigns for truck drivers.
Medium-Term (1–3 Years)	Redesign hazardous intersections with channelization and rumble strips; strengthen nighttime lighting and signage on rural stretches.
Long-Term (3–5 Years)	Integrate predictive crash monitoring using real-time traffic feeds; establish dedicated two-wheeler lanes on high-volume corridors.

7. Conclusions

Highway crashes in Madhya Pradesh have grown in both frequency and severity over the last seven years, with over-speeding, lane indiscipline, and driver fatigue emerging as key determinants. GIS-based black-spot mapping and predictive modeling provide powerful tools for targeted enforcement and infrastructure upgrades. Implementation of AI-driven monitoring, improved road geometry, and community-centered awareness programs can significantly reduce accidents and support India's commitment to halving road traffic deaths by 2030.

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