Recent Advances in Computational Methods for Road Traffic Accident Analysis - A Comprehensive Literature Review

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Abstract- *Road traffic accidents cause considerable loss of life, economic cost, and social disruption worldwide. As transportation data has become more available and computational methods have advanced, researchers have increasingly turned to machine learning, deep learning, geospatial analytics, and intelligent transportation systems to study accident patterns and traffic safety. This review examines recent computational approaches to road traffic accident research, looking at the objectives, datasets, methods, and key findings of existing studies across areas such as accident severity prediction, hotspot identification, traffic flow analysis, real-time accident detection, transfer learning, explainable artificial intelligence, and graph-based learning. It draws out the range of data sources and analytical techniques used across different transportation settings and traces how predictive and spatial methods in road safety research have evolved. By bringing this literature together, the paper offers a consolidated view of current methodological developments and emerging trends in data-driven accident analysis, intended as a reference for researchers, transportation planners, and policymakers working on transportation safety.*

Keywords: Road Traffic Accidents; Machine Learning; Deep Learning; Intelligent Transportation Systems; Traffic Safety; Geospatial Analytics; Explainable Artificial Intelligence; Transportation Analytics.

1. INTRODUCTION

Road traffic accidents are among the leading causes of death and injury worldwide, and they pose ongoing challenges for public health, transportation systems, and economic development. National and international road safety reports point to rising vehicle ownership, rapid urbanization, expanding road infrastructure, and growing traffic volumes as key drivers behind the steady increase in accidents across many countries. Beyond the loss of life, these accidents carry substantial economic costs, disrupt transportation networks, and produce lasting social consequences. Improving road safety has, as a result, become a priority for governments, transportation authorities, urban planners, and researchers alike.

Over the past several years, growing access to transportation-related data and advances in computational technology have changed how road accident analysis is done. Machine learning, deep learning, geospatial analytics, and intelligent transportation systems now sit alongside traditional statistical methods, making it possible to analyze complex accident patterns across large transportation datasets. These techniques have been applied to accident severity analysis, traffic flow prediction, hotspot identification, risk assessment, driver behavior analysis, emergency response planning, and real-time accident detection. Their capacity to surface hidden relationships in heterogeneous data has meaningfully improved data-driven decision-making in transportation safety.

Machine learning methods such as Decision Trees, Random Forests, Support Vector Machines, Gradient Boosting, and Artificial Neural Networks have shown real promise for accident prediction and classification. More recently, deep learning architectures, including Convolutional Neural Networks (CNNs), Long Short-Term Memory (LSTM) networks, Graph Neural Networks (GNNs), and hybrid models, have been used to capture the spatial and temporal relationships within transportation data. Geographic Information Systems (GIS) have also become a standard tool for visualizing accident distributions, identifying spatial hotspots, and supporting infrastructure planning through location-based analysis. Newer developments such as transfer learning and explainable artificial intelligence have expanded this toolkit further, improving how well models adapt and how easily their results can be interpreted.

This growth in computational methods has produced a wide body of literature spanning different transportation environments, datasets, objectives, and methodological approaches. Individual studies have looked at accident severity prediction, hotspot mapping, traffic forecasting, emergency management, driver behavior analysis, and intelligent transportation applications, drawing on statistical, machine learning, deep learning, and geospatial techniques. As the field keeps evolving, a consolidated review of these approaches offers useful insight into current methodological developments and how computational techniques in road accident analysis have progressed.

This paper reviews recent studies on machine learning, deep learning, geospatial analytics, and intelligent transportation systems as applied to road traffic accident analysis, examining each in terms of research objectives, datasets, methodology, and principal findings. Rather than focusing on any single method, the review aims to summarize the range of techniques used across the literature and trace how data-driven approaches in transportation safety research have developed.

The rest of the paper is organized as follows. Section 2 reviews the individual studies, covering their research focus, data sources, analytical techniques, findings, and future scope. Section 3 brings these studies together in a comparative summary table for quick reference. Section 4 draws out the broader research trends across the literature, machine learning, deep learning, GIS-based spatial analysis, and explainable AI. Section 5 concludes the paper and reflects on where the field is headed.

2. LITERATURE REVIEW

Machine learning, deep learning, geospatial analytics, and intelligent transportation systems have reshaped road traffic accident analysis over the past decade. Researchers have increasingly turned to computational techniques to study accident severity, traffic flow, hotspot identification, emergency response planning, driver behavior, and spatiotemporal traffic patterns. Growing access to transportation datasets, combined with advances in artificial intelligence and geographic information systems, has enabled increasingly sophisticated analytical models for transportation safety. This section reviews representative studies that have contributed to computational approaches in road accident analysis, looking at their objectives, datasets, methodologies, and principal findings.

Sorum and Pal (2024) looked at driver injury severity prediction in the hilly urban environments of Itanagar and Imphal in Northeast India. Using accident-report datasets, they evaluated twelve supervised machine learning algorithms, including Gradient Boosting Trees (GBT), Extra Trees, Random Forest, and other ensemble methods, with k-fold cross-validation for performance assessment. Gradient Boosting Trees achieved the highest predictive performance among the models tested, and Cause of Accident and Vehicle Type emerged as the most influential variables affecting injury severity. The results point to the value of ensemble machine learning techniques for analyzing accident severity in mixed traffic environments.

Khanum, Garg, and Faheem (2023) worked on accident severity prediction using highway accident datasets from the Ministry of Road Transport and Highways (MoRTH) and the National Highways Authority of India (NHAI). Their focus was the class imbalance common in accident datasets, which they addressed with Random Forest classifiers combined with grid-search optimization. The results underline how much preprocessing and model optimization matter for classification accuracy when working with imbalanced transportation data. The authors recommended improving strategies for handling class imbalance and evaluating the proposed framework using temporally updated and geographically diverse accident datasets. For future research, the authors suggested incorporating spatial or GIS-based information into injury severity models and updating the dataset with more recent accident records to better represent changing traffic conditions.

Srivastava, Prakash, and Shivakumar (2024) analyzed long-term road accident trends in India using accident statistics spanning several decades, comparing Linear Regression, Nonlinear Regression, and Multi-Layer Perceptron Neural Networks (MLPNN) for accident prediction. MLPNN outperformed the conventional regression models, reaching an R^2 value of approximately 88%, which suggests that neural network models can capture complex relationships in long-term transportation data that simpler regression approaches miss. For future research, the authors suggested extending accident prediction studies to more localized spatial analyses for improved understanding of regional accident patterns.

Bharadwaj, Nair, and Bhat (2022) built a predictive framework for road accident analysis across Indian states and union territories, combining predictive modelling with clustering to classify regions by accident risk level. This approach let them group regions into different risk categories, giving transportation authorities useful input for administrative planning and resource allocation. For future research, the authors recommended exploring advanced deep learning approaches and enhancing predictive analysis using more detailed transportation datasets.

Sharma and Gupta (2024) examined road accident fatalities and safety trends in Rajasthan using accident records from 2015 to 2023, looking at factors including over-speeding, vehicle registration growth, road infrastructure expansion, and seasonal accident variation. Over-speeding remained one of the major contributors to fatalities, and individuals between 25 and 45 years old made up a significant share of affected road users. The study offers a detailed statistical picture of recent road safety trends in the state. For future research, the authors emphasized the need for extending descriptive accident analysis through predictive analytical approaches using advanced computational techniques.

Khan and Kayamkhani (2014) carried out a district-wise assessment of road accident severity across Rajasthan using government accident statistics, applying indices such as the Fatality Risk Index and Severity Index. The analysis found considerable regional variation in accident severity, with several highway-connected districts showing relatively higher fatality rates, offering a useful statistical reference for regional road safety analysis in Rajasthan. For future research, the authors highlighted the importance of developing improved accident monitoring and analytical approaches for supporting road safety planning.

Dandabathula, Roy, Bera, and Srivastav (2024) investigated emergency medical service accessibility along the Jaipur–Jodhpur highway corridor using GIS-based network analysis, assessing trauma care accessibility across roughly 805 km of highway by estimating travel times within the critical emergency response window. Urban locations had notably better emergency service coverage than rural areas, showing how GIS-based network analysis can be used to evaluate transportation infrastructure and emergency response planning. For future research, the authors suggested integrating GPS-based road information and real-time environmental factors to improve emergency response assessment.

Yang et al. (2023) proposed a Cross-City Accident Risk Prediction framework built on Graph Neural Networks (GNNs) and attentive region-level parameter generation, evaluating it on traffic accident datasets from New York and Chicago to test how well learned representations transfer across urban regions. Prediction performance improved when the model drew on knowledge from multiple cities, supporting the case for graph-based deep learning in traffic accident prediction across varied transportation environments. For future research, the authors recommended extending knowledge transfer approaches to finer regional levels and evaluating the framework across additional transportation environments.

Du et al. (2024) introduced a Physics-Guided Multi-Source Domain Adaptation Neural Network (PG-MDAN) for traffic flow prediction, incorporating the Macroscopic Fundamental Diagram (MFD) into a deep learning architecture to improve accuracy across different traffic networks. Combining domain knowledge with neural network models improved the framework's reliability, pointing to the potential of physics-guided learning for intelligent transportation applications. For future research, the authors suggested validating the proposed framework across diverse transportation infrastructures and heterogeneous traffic networks.

Yuan et al. (2022) developed a real-time traffic accident anticipation framework that combines graph sparse coding with spatiotemporal modelling, analyzing dashcam video sequences to spot abnormal driving behaviors such as sudden braking, lane deviations, and rapid vehicle interactions that often precede accidents. Their evaluation showed the approach could give early accident warnings through continuous analysis of dynamic traffic conditions. For future research, the authors recommended extending the framework to broader transportation forecasting scenarios and evaluating its performance using diverse real-world datasets.

Li and Chen (2025) proposed a hybrid deep learning framework combining Convolutional Neural Networks (CNN), Long Short-Term Memory (LSTM) networks, and Graph Neural Networks (GNN) for traffic accident risk prediction, pairing spatial roadway characteristics with temporal vehicle movement data from trajectory datasets. In comparative experiments, this hybrid architecture achieved higher prediction accuracy than individual deep learning models by capturing both spatial and temporal dependencies at once. For future research, the authors recommended evaluating the proposed framework using larger vehicle trajectory datasets collected under diverse traffic conditions.

Alhaek et al. (2024) presented a sparse spatiotemporal learning framework based on Bidirectional Long Short-Term Memory (BiLSTM) networks and attention mechanisms for accident forecasting in urban settings, designed to work with incomplete historical traffic data while preserving temporal relationships between accident events. Their results show that attention-based deep learning can improve forecasting performance even in data-sparse scenarios. For future research, the authors suggested improving computational efficiency and enhancing model generalization for application across diverse transportation environments.

Bisht et al. (2023) compared multiple geospatial hotspot detection techniques for identifying accident-prone locations on Indian expressways, evaluating Ordinary Kriging, Kernel Density Estimation (KDE), and Network Kernel Density Estimation (Network KDE) using GIS tools. Network KDE produced the most accurate hotspot identification by factoring in roadway geometry, which points to the importance of geospatial techniques for accident hotspot visualization and transportation safety assessment. For future research, the authors recommended extending geospatial hotspot identification techniques to more complex transportation networks and varied roadway environments.

Behboudi, Moosavi, and Ramnath (2024) reviewed a large body of published research on traffic accident prediction, covering accident severity prediction, hotspot detection, accident frequency modelling, and real-time traffic analysis. Their review traces the evolution of computational approaches from traditional machine learning algorithms through deep learning models, Graph Neural Networks, and attention-based architectures, offering a broad picture of current methodological developments in traffic accident analysis. For future research, the authors highlighted future opportunities involving richer multimodal datasets, Explainable AI, Graph Neural Networks, Transformer architectures, self-supervised learning, and integration with intelligent transportation systems.

Khanum, Garg, Faheem, and Kulkarni (2025) proposed a machine learning framework built around SHAP (SHapley Additive exPlanations) for interpreting accident severity prediction models, using ensemble techniques such as Random Forest and Gradient Boosting alongside feature importance analysis. Vehicle type, weather conditions, and roadway surface characteristics stood out as the most influential variables affecting accident severity, demonstrating what explainable AI can add to transportation analytics. For future research, the authors recommended extending accident severity analysis to more granular transportation datasets and incorporating GPS-referenced information for improved predictive modelling.

Sandhu, Singh, Sisodia, and Chauhan (2016) conducted a GIS-based investigation of accident black spots along the NH-8 corridor connecting Delhi, Gurgaon, and Jaipur, applying Kernel Density Estimation (KDE), Moran's I spatial autocorrelation, and Getis–Ord Gi* statistics within ArcGIS to identify statistically significant accident clusters. The results confirm that spatial statistical techniques can effectively visualize accident-prone locations and support transportation planning and road safety management. For future research, the authors emphasized the need for scalable and automated spatial accident monitoring techniques to support large-scale road safety management.

3. COMPARATIVE SUMMARY OF REVIEWED STUDIES

Table1. Comparative Summary of Representative Studies on Road Traffic Accident Analysis

Authors	Study Focus	Data Source	Analytical Technique	Major Findings	Future Scope
Sorum and Pal (2024)	Driver injury severity prediction	Accident report datasets from Northeast India	Gradient Boosting Trees, Random Forest, Extra Trees and other ML algorithms	Gradient Boosting Trees achieved the highest prediction performance, with accident cause and vehicle type identified as influential variables.	Integration of spatial or GIS-based information into injury severity prediction models and incorporation of post-2020 accident records to better capture evolving traffic conditions.
Khanum, Garg and Faheem (2023)	Accident severity prediction	MoRTH and NHAI highway datasets	Random Forest with Grid Search Optimization	Preprocessing and parameter optimization improved classification performance on imbalanced accident datasets.	Development of improved techniques for handling class imbalance and evaluation of the proposed framework using temporally updated and geographically diverse accident datasets.
Srivastava, Prakash and Shivakumar (2024)	Long-term accident trend prediction	National road accident statistics	Linear Regression, Non-linear Regression, MLPNN	MLPNN outperformed conventional regression models in accident prediction.	Extension of accident prediction studies to more localized spatial analyses for identifying regional accident patterns and high-risk locations.
Bharadwaj, Nair and Bhat (2022)	Accident risk classification	Indian state-level accident statistics	Predictive modelling and clustering	Regional risk categorization supported transportation planning and administrative decision-making.	Exploration of advanced deep learning techniques and incorporation of localized road network information to enhance accident prediction and classification.
Sharma and Gupta (2024)	Road safety trend analysis	Rajasthan accident records (2015–	Statistical analysis	Over-speeding and seasonal	Extension of descriptive road

		2023)		variations were identified as major contributors to accident fatalities.	safety analysis through predictive analytical approaches using advanced computational techniques.
Khan and Kayamkhani (2014)	District-wise accident severity assessment	Rajasthan government accident statistics	Fatality Risk Index and Severity Index	Considerable variation in accident severity was observed across different districts.	Development of improved accident monitoring and analytical approaches to support evidence-based road safety planning and management.
Dandabathula et al. (2024)	Emergency healthcare accessibility	Jaipur–Jodhpur highway corridor	GIS-based network analysis	Significant differences were observed in trauma care accessibility across the highway corridor.	Integration of GPS-referenced road information with real-time environmental factors, such as weather conditions, to strengthen emergency response assessment.
Yang et al. (2023)	Cross-city traffic accident prediction	Urban traffic datasets	Graph Neural Networks	Cross-city learning improved accident prediction performance.	Extension of knowledge transfer frameworks to finer regional levels and evaluation across additional data-scarce transportation environments.
Du et al. (2024)	Traffic flow prediction	Multi-source traffic datasets	Physics-guided deep learning	Integration of transportation flow characteristics improved prediction accuracy.	Validation of physics-guided domain adaptation models across diverse transportation infrastructures and heterogeneous traffic networks.
Yuan et al. (2022)	Real-time accident anticipation	Dashcam video datasets	Graph sparse coding and	Early identification of	Extension of

			spatiotemporal modeling	abnormal driving behaviour enhanced accident anticipation.	the proposed framework to broader transportation forecasting applications using large-scale real-world traffic datasets.
Li and Chen (2025)	Traffic accident risk prediction	Vehicle trajectory datasets	CNN–LSTM–GNN hybrid model	Hybrid deep learning architecture improved accident prediction accuracy.	Evaluation of the hybrid deep learning framework using larger vehicle trajectory datasets collected under diverse traffic conditions.
Alhaek et al. (2024)	Sparse traffic accident forecasting	Urban traffic datasets	BiLSTM with attention mechanism	Attention-based learning effectively analysed sparse transportation data.	Improvement of computational efficiency and enhancement of model generalization for application across varied transportation environments with sparse accident data.
Bisht et al. (2023)	Accident hotspot detection	Expressway accident datasets	Ordinary Kriging, KDE and Network KDE	Network KDE produced effective spatial hotspot identification.	Extension of Network Kernel Density Estimation (NKDE) techniques to more complex urban transportation networks and diverse roadway environments.
Behboudi, Moosavi and Ramnath (2024)	Review of accident prediction studies	Published research literature	Systematic literature review	Summarized recent computational approaches in traffic accident prediction.	Exploration of richer multimodal datasets, Explainable AI (XAI), Graph Neural Networks, Transformer

					architectures, self-supervised learning, and integration with intelligent transportation systems.
Khanum et al. (2025)	Explainable accident severity prediction	Highway accident datasets	Random Forest, Gradient Boosting and SHAP	Explainable AI improved interpretation of machine learning models.	Extension of accident severity analysis to more granular transportation datasets with the incorporation of GPS-referenced information for enhanced predictive modelling.
Sandhu et al. (2016)	Black spot identification	NH-8 accident records	GIS, Kernel Density Estimation, Moran's I and Getis–Ord Gi*	GIS-based spatial analysis effectively identified accident-prone locations.	Development of scalable and automated GIS-based accident hotspot identification techniques for supporting large-scale road safety management.

4. RESEARCH TRENDS IN ROAD TRAFFIC ACCIDENT ANALYSIS

Machine learning remains one of the most widely used computational approaches in road traffic accident analysis. Traditional algorithms, including Decision Trees, Random Forests, Support Vector Machines, Gradient Boosting, and Artificial Neural Networks, have been applied successfully to accident severity prediction, risk assessment, and traffic classification. Ensemble methods, particularly Random Forest and Gradient Boosting, tend to perform well across diverse transportation datasets because they can model complex relationships among accident-related variables.

Deep learning techniques are seeing increasing use in transportation safety analysis. Architectures such as Convolutional Neural Networks (CNN), Long Short-Term Memory (LSTM) networks, Bidirectional LSTM, and Graph Neural Networks (GNN) make it possible to model the spatial and temporal relationships within traffic datasets. Hybrid frameworks that combine multiple architectures have pushed predictive performance further by drawing on complementary feature learning capabilities.

Geographic Information Systems (GIS) have become a standard analytical tool in road traffic accident studies. Spatial techniques such as Kernel Density Estimation, Network Kernel Density Estimation, Moran's I, Getis–Ord Gi*, and network analysis are widely used for hotspot identification, spatial visualization, accessibility assessment, and transportation planning, helping researchers interpret the geographical distribution of road accidents.

Recent transportation studies increasingly build in explainability techniques to make machine learning models easier to interpret. Methods such as SHAP (SHapley Additive exPlanations) help researchers identify which variables most influence accident prediction, improving model transparency and supporting better-informed decisions in transportation safety.

The literature also shows growing integration between intelligent transportation systems and artificial intelligence. Applications in traffic flow prediction, accident anticipation, emergency response analysis, and graph-based transportation modelling reflect the expanding role of data-driven technologies in modern transportation management.

5. CONCLUSION

Road traffic accident analysis has advanced considerably with the growing use of computational techniques in transportation research. The literature reviewed here shows that machine learning, deep learning, geospatial analytics, and intelligent transportation systems have become important tools for analyzing accident severity, traffic patterns, hotspot identification, traffic flow, emergency response, and transportation safety more broadly. As transportation data keeps growing, so does the use of artificial intelligence to support evidence-based decision-making and improve road safety management.

The studies reviewed draw on a wide range of analytical approaches, including traditional machine learning algorithms, ensemble learning techniques, deep learning architectures, graph-based models, explainable artificial intelligence, and GIS-based spatial analysis, applied across different transportation environments and data sources such as accident reports, highway databases, traffic flow records, vehicle trajectory data, dashcam videos, and geospatial information. Together, they show how much computational intelligence now contributes to understanding accident characteristics and supporting transportation planning.

The literature also points to growing integration between advanced analytical methods and transportation applications. Recent work on hybrid deep learning models, graph neural networks, attention mechanisms, transfer learning, explainable artificial intelligence, and spatial analytical techniques suggests that road accident research keeps moving toward more sophisticated, data-driven analytical frameworks. This has broadened the computational toolkit available for traffic safety analysis and transportation management.

This review brings together contemporary computational approaches to road traffic accident analysis, drawing on studies that apply different methodologies across varied transportation contexts to offer a consolidated reference for researchers, transportation professionals, and policymakers interested in data-driven road safety research. In doing so, it presents an organized synthesis of existing work and highlights the range of computational techniques now used in transportation safety studies.

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