A Comprehensive Review and Comparative Evaluation of Pedestrian Crash Prediction Approaches

Soja R. Joseph

Department of Civil Engineering, Jyothi Engineering College, Thrissur, Kerala, India

Sanjay Kumar V. S.

Principal Scientist & Head Traffic Engineering & Safety Division KSCSTE, NATPAC, Thiruvananthapuram, Kerala, India

Archana S.*

Assistant Professor, Department of Civil Engineering, Jyothi Engineering College, Thrissur, Kerala, India

Jinumol K. R.

Project Fellow, Traffic Engineering & Safety Division KSCSTE, NATPAC, Thiruvananthapuram, Kerala, India

* Corresponding author

doi: https://doi.org/10.21467/proceedings.179.34

ABSTRACT

Road crashes represent a significant public health concern, causing immense human suffering and economic losses worldwide. Vulnerable road users, such as pedestrians, cyclists, three-wheelers and motorcyclists, account for half of all deaths on roadways. Among them, pedestrians alone contribute to more than half of all fatalities, highlighting the severity of the dangers they face. Crash prediction studies play an important role in identifying high-risk areas and implementing measures to mitigate pedestrian crashes, thus actively contributing to the reduction of pedestrian fatalities and injuries on roadways. Through a comprehensive literature review, it was found that during the 1960s, pedestrian safety studies gained prominence, indicating a significant shift in recognizing the importance of pedestrian safety. Statistical models such as Multiple Linear Regression, Poisson Regression, and Negative Binomial Regression were introduced to analyze the relationship between pedestrian crashes and various factors, including traffic volume, road characteristics, and environmental variables. Moreover, recent advancements in machine learning have enhanced the accuracy and predictive capabilities of pedestrian crash prediction models. The present review paper explains a comparative analysis between statistical modeling and machine learning modeling as applied to crash prediction modeling. Machine learning models, adept at handling large and complex datasets, generally offer higher predictive accuracy compared to statistical models, which are more suitable for smaller datasets and understanding causal relationships. In both statistical modeling and machine learning approaches, common parameters such as traffic volume, road characteristics, and environmental variables are utilized for pedestrian crash prediction, while the consideration of pedestrian behaviour factors remains limited.

1. Introduction

Road crashes are a major global health issue, encompassing collisions between vehicles, pedestrians, animals, and stationary objects such as trees or poles. These incidents often result from a complex interplay of human, vehicle, and environmental factors, with common causes including speeding, distracted driving, adverse weather conditions, and driver fatigue. The consequences of road crashes are severe, frequently leading to injuries, fatalities, and substantial property damage. Among the various types of road crashes, pedestrian safety is of particular concern due to the vulnerability of pedestrians in these incidents.

Proceedings DOI: 10.21467/proceedings.179; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-984081-7-4

Historically, the evolution of pedestrian safety research has been marked by significant milestones. The first recorded motor vehicle fatality occurred in 1869, followed by the first pedestrian fatality in 1896. Ensuring pedestrian safety is critical for developing safer urban environments and requires a multi-faceted approach involving scientific research, improved road design, and public awareness initiatives. The development of pedestrian crash prediction models has become essential in proactively identifying high-risk areas and implementing preventive strategies. Initially, these models relied on simple statistical approaches using historical data and key contributing factors. Over time, advancements in technology and data availability have led to more sophisticated models incorporating regression analyses and, more recently, machine learning techniques. Early statistical methods, such as Multiple Linear Regression (MLR), Poisson Regression, and Negative Binomial Regression, focused on analyzing how factors like traffic volume, road characteristics, and environmental conditions affect pedestrian crashes.

As technology evolved, machine learning techniques, including decision trees and deep learning, emerged, and offering improved predictive accuracy and the ability to manage complex datasets. Recent research has further advanced pedestrian safety through various methodologies. For instance, Bayesian spatial modeling has been used to assess how road network patterns impact pedestrian safety. Studies have also examined injury severity at different locations and identified risk factors at urban intersections, while others have focused on predictive models and severity assessments using parametric and non-parametric analyses. The application of machine learning has transformed pedestrian crash prediction, with artificial neural networks enhancing predictions in developing countries, and classification tools improving pattern recognition of pedestrian crashes. These advancements underscore the potential of artificial intelligence to refine pedestrian fatality predictions and enhance safety outcomes. Additionally, integrating spatial analysis and Geographic Information Systems (GIS) has refined predictive models, allowing targeted interventions in specific areas. For example, crowdsourced data from Eastern Cairo identified high-risk spots and guided safety improvements. Despite these advancements, challenges remain, particularly in regions with limited infrastructure and data.

2. Scope and Objective

The scope of this study is limited to examining pedestrian crash prediction models from 1960 to 2023. The primary objective of this review paper is to identify and compare the parameters, methodologies, and evaluation metrics employed in statistical and machine learning approaches for pedestrian crash prediction.

3. Methodology

To achieve the study objective, a comprehensive literature review was conducted to gather and analyze pedestrian crash prediction models which were developed from 1960 to 2023. The review focused on identifying and comparing the parameters, methodologies, and evaluation metrics used in both statistical and machine learning approaches. Initially, relevant studies were collected from academic journals, conference papers, and industry reports. Key parameters affecting pedestrian safety were documented and categorized, and performance metrics for each approach were assessed. A comparison was performed to identify trends and evaluate the efficiency of different modeling techniques.

4. Results & Analysis

4.1 Statistical Modelling Approaches

Statistical methods in pedestrian crash prediction modeling play a crucial role in understanding and forecasting the occurrence of pedestrian-related crashes. These models help identify significant predictors, such as traffic volume, road characteristics, and pedestrian activity, by estimating the relationship between

Proceedings DOI: 10.21467/proceedings.179
ISBN: 978-81-984081-7-4

Series: AIJR Proceedings
ISSN: 2582-3922

these factors and crash frequency. The analysis of different parameters used in statistical pedestrian crash prediction modeling across various studies reveals a diverse set of factors influencing pedestrian safety. Table 1 reveals that most studies focused on road-related parameters, including the number of lanes, area type, and pedestrian-specific infrastructure such as crosswalks, footpaths, and pedestrian signals. Features like foot over bridges and subways were rarely considered. Traffic parameters, including vehicular traffic, were frequently analyzed, whereas pedestrian traffic and pedestrian signals appeared in fewer studies. Commonly examined factors included road surface type, divided or undivided road status, and street lighting, emphasizing the influence of road design on pedestrian safety. However, parameters like traffic calming measures, signboards, road markings, and pedestrian refuge islands were less frequently analyzed. Studies addressing pedestrian behavior parameters were notably limited. Furthermore, many studies focused on specific locations or junctions. This variability in the parameters used across studies highlights the complexity of pedestrian safety and underscores the need for a more comprehensive and consistent approach to crash prediction modeling.

Table 1. Parameter Matrix for Statistical Modelling

Parameters	Davis et al. (1989)	Shankar N. V., et al. (2003)	Sze & Wong (2007)	Haleem et al. (2015)	Khan & Rahman	Guo (2017)	Zhai et al. (2019)	Mukherjee & Mitra (2020)	Riccardi et al. (2022)	Elalouf et al. (2023)
Footpath	✓		✓		✓		✓	✓	✓	
Crosswalk	✓	✓		✓	✓			✓	✓	✓
Pedestrian Signal		✓		✓				✓		
Pedestrian refuge				✓					✓	
Foot over bridge								✓		
Subway								✓		
No. of Lanes	✓	✓	✓							✓
One Way/Two Way		✓	✓				✓		✓	✓
Streetlighting		✓		✓				✓	✓	✓
Median		✓			✓			✓		✓
Divided/Undivided			✓		✓					
Carriageway Width			✓					✓	✓	✓
Speed limit			✓	✓					✓	
Road Surface Type				✓		✓		✓	✓	✓
Area type				✓		✓			✓	✓

Land Use				✓		✓		✓		✓
Shoulder					✓					✓
Bus Stop					✓			✓		✓
Lane Width								✓		✓
Parking								✓		
Sign Boards								✓	✓	✓
Road Markings								✓		✓
Speed Calming										✓
Vehicular Traffic	✓	✓		✓		✓		✓		
Pedestrian Traffic	✓							✓		

The analysis of statistical methods utilized in pedestrian crash prediction modeling, as shown in Table 2, highlights the wide range of approaches adopted in various studies. Poisson and Negative Binomial Regression models are among the most commonly used, demonstrating their effectiveness in handling count data, particularly when overdispersion is present. Advanced techniques such as Mixed Logit Models and Multinomial Logit Models are applied to capture individual-specific heterogeneity, making them particularly useful for modeling choices or probabilities associated with pedestrian crashes. Logistic Regression, along with its variants like Ordered and Multinomial Logit Models, is frequently employed to predict the likelihood of crashes occurring under different conditions. Additionally, Bayesian Poisson-lognormal models and Random Parameter models offer a flexible framework for addressing uncertainty and unobserved heterogeneity within the data. The diversity of statistical modeling techniques reflects the complexity of pedestrian crash prediction and emphasizes the importance of selecting methods suited to the specific characteristics and requirements of the data.

Table 2. Methodology Matrix for Statistical Modelling

Methods	Davis et al. (1989)	Shankar N. V., et al. (2003)	Sze & Wong (2007)	Haleem et al. (2015)	Khan & Rahman (2016)	Guo (2017)	Zhai et al. (2019)	Mukherjee & Mitra (2020)	Riccardi et al. (2022)	Elalouf et al. (2023)
Discriminant Analysis	✓									
Poisson Regression		✓				✓		✓		
Negative Binomial Regression		✓						✓		
Logistic Regression			✓							✓

Mixed Logit Models	✓	✓		✓		
Random parameter negative binomial (RPNB) models		✓				
Poisson-Gamma-CAR model		✓				
Bayesian Poisson-lognormal (PLN)			✓			
Ordered Logit Models						✓
Multinomial Logit Models						✓
Random parameter multinominal logit models						✓
Random parameter ordered logit models						✓

Common metrics such as Mean Squared Error (MSE) and Root Mean Squared Error (RMSE) are widely used to evaluate the accuracy of predictive models, providing insight into the average magnitude of errors. Advanced metrics like McFadden's Pseudo R^2 and Akaike Information Criterion (AIC) assess the model's explanatory power and goodness of fit, particularly in regression-based analyses. Classification performance is evaluated using metrics such as precision, recall, F1 score, and sensitivity, often derived from the confusion matrix. Metrics like the Area Under the Curve (AUC) and G-mean offer a more comprehensive assessment of the model's ability to discriminate between different outcomes. These evaluation criteria are vital for comparing models and selecting the most reliable and robust approach for pedestrian crash prediction.

Table 3. Evaluation Methods Matrix for Statistical Modelling

Evaluation Criteria	Davis et al. (1989)	Shankar N. V., et al. (2003)	Sze & Wong (2007)	Haleem et al. (2015)	Khan & Rahman (2016)	Guo (2017)	Zhai et al. (2019)	Mukherjee & Mitra (2020)	Riccardi et al. (2022)	Elalouf et al.
Accuracy	✓									✓
Log-Loss		✓				✓		✓		
MSE		✓								
Hosmer–Lemeshow statistic			✓							

Akaiki Information Criterion (AIC)	✓				✓		
McFadden's Pseudo R^2	✓						
R-squared					✓		
F-measure						✓	
G-mean						✓	
AUC						✓	
Precision							✓
Recall							✓
F1 Score							✓

4.2 Machine Learning Techniques

Machine learning techniques have increasingly been employed in pedestrian crash prediction modeling to enhance accuracy and predictive capability. By leveraging large datasets and sophisticated algorithms, these approaches identify patterns and correlations that traditional methods might overlook. From Table 4, key parameters used in modeling include road category, area type, and road surface type, which characterize the fundamental attributes of the environment. Factors such as the number of lanes, presence of a median, and lane width provide crucial information about road configuration. Additionally, the presence and type of pedestrian infrastructure—such as crosswalks, footpaths, pedestrian signals, and street lighting—underscore their importance in ensuring pedestrian safety. Variables like vehicular traffic, pedestrian traffic, speed limits, and speed calming devices highlight the dynamic nature of pedestrian risk.

Table 4.Parameter Matrix for Machine Learning Modelling

Parameters	Alireza et al (2016)	Mostafizur et al. (2018)	Chakraborty et al. (2019)	Rahman et al. (2019)	Das et al. (2020)	Meocci et al. (2021)	Tao et al. (2022)	Riccardi et al. (2022)	Ul Arifeen et al. (2023)	Elalouf et al. (2023)
Pedestrian Signal	✓	✓				✓				
Crosswalk			✓		✓	✓		✓		✓
Footpath				✓	✓			✓		
No. of Lanes	✓					✓				✓
One Way/Two Way	✓					✓		✓		✓
Lane Width	✓			✓						✓

Proceedings DOI: 10.21467/proceedings.179
ISBN: 978-81-984081-7-4

Series: AIJR Proceedings
ISSN: 2582-3922

Road Surface Type	✓					✓		✓	✓	✓
Median	✓				✓					✓
Land Use	✓		✓							✓
Speed limit	✓	✓					✓	✓		
Streetlighting	✓	✓							✓	✓
Area type		✓		✓		✓		✓		✓
Road Category		✓					✓			
Sign Boards		✓								✓
Night-Time Visibility		✓								✓
Shoulder					✓					✓
Speed Calming Devices						✓			✓	✓
Parking						✓		✓		
Bus Stop						✓	✓	✓		✓
Drainage								✓		
Carriageway Width								✓		✓
Road Markings								✓	✓	✓
Vehicular Traffic	✓		✓			✓				
Pedestrian Traffic			✓							

Commonly used methods include classification trees, random forests, and artificial neural networks, which are effective in handling complex, nonlinear relationships in crash data. Support vector machines and K-nearest neighbors offer flexibility in modeling diverse data distributions and high-dimensional features. Advanced ensemble methods, such as Gradient Boosting, XGBoost, and the CatBoost algorithm, combine multiple models to enhance predictive accuracy and generalization. Techniques like Naive Bayes and its variants, including Gaussian Naive Bayes, provide simplicity and efficiency in probabilistic modeling.

Proceedings DOI: 10.21467/proceedings.179
ISBN: 978-81-984081-7-4

Series: AIJR Proceedings
ISSN: 2582-3922

Table 5. Methodology Matrix for Machine Learning Modelling

Techniques	Alireza et al (2016)	Mostafizur et al. (2018)	Chakraborty et al. (2019)	Rahman et al. (2019)	Das et al. (2020)	Meocci et al. (2021)	Tao et al. (2022)	Riccardi et al. (2022)	Ul Arifeen et al. (2023)	Elalouf et al. (2023)
Decision Tree	✓			✓						✓
Random Forests		✓		✓	✓		✓	✓	✓	
Support Vector Machines		✓			✓			✓		✓
K-Nearest Neighbour (KNN)		✓								✓
Standard Neural Networks		✓					✓		✓	
Bayesian neural network		✓					✓			✓
Artificial Neural Networks			✓					✓		✓
XG Boost					✓					
CatBoost Algorithm						✓				
Association Rules								✓		
Classification Trees								✓		
Linear SVC										✓
Naive Bayes										✓
Gaussian Naive Bayes										✓
Ridge Classifier										✓
Ridge Classifier CV										✓
Extra Tree Classifier										✓
Perceptron Algorithm										✓

From Table 6, the evaluation metrics used across various studies in pedestrian crash prediction modeling reflect a comprehensive approach to assessing model performance. Metrics such as F-measure, G-mean, and ROC AUC evaluate the overall effectiveness and robustness of models in distinguishing between crash and non-crash events. Accuracy, precision, recall (sensitivity), and the F1 score offer insights into the model's ability to classify instances correctly and manage imbalanced data. Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE) measure prediction accuracy and error magnitude, while R-squared and Matthew's Correlation Coefficient (MCC) assess prediction quality and the strength of association. Specificity and Balanced Accuracy focus on model performance across different classes.

Table 6. Evaluation Methods Matrix for Machine Learning Modelling

Evaluation Criteria	Alireza et al (2016)	Mostafizur et al.	Chakraborty et al.	Rahman et al.	Das et al. (2020)	Meocci et al. (2021)	Tao et al. (2022)	Riccardi et al.	Ul Arifeen et al.	Elalouf et
Accuracy	✓	✓		✓	✓	✓	✓			✓
Recall/ Sensitivity	✓	✓		✓	✓	✓			✓	✓
AUC	✓						✓	✓	✓	
Precision		✓		✓	✓	✓				✓
F1 Score		✓		✓	✓		✓		✓	✓
Specificity		✓		✓	✓				✓	
Root Mean Squared Error (RMSE)			✓							
Mean Absolute Error (MAE)			✓							
R-squared			✓							
Balanced Accuracy					✓					
Matthew's correlation coefficient (MCC)							✓		✓	
F-measure								✓		
G-mean								✓		
ROC									✓	

5. Conclusions

The evolution of pedestrian crash prediction models from the 1960s to 2023 reflects significant advancements in both methodology and technology. Early studies primarily focused on statistical models, such as Poisson and Negative Binomial regressions, which effectively handled count data with overdispersion. Advanced statistical approaches, like Mixed Logit and Multinomial Logit models, captured individual-specific heterogeneity and were instrumental in modeling crash probabilities. Models such as Logistic Regression, along with Bayesian and Random Parameter models, provided flexible approaches for accounting for uncertainty and unobserved factors. These models, commonly using parameters like road category, number of lanes, and traffic volume, laid the foundation for pedestrian safety analysis. In recent years, machine learning techniques such as Random Forest, Artificial Neural Networks (ANN), Support Vector Machines (SVM), and Decision Trees have been increasingly employed. These methods are particularly adept at handling complex, nonlinear relationships within large datasets and have improved predictive accuracy. Ensemble methods like XGBoost and Gradient Boosting have further enhanced model performance by combining multiple models to make more accurate predictions. While statistical models tend to focus on simpler, interpretable approaches, machine learning models utilize sophisticated algorithms to uncover hidden patterns and relationships. Common evaluation metrics used in both approaches include accuracy, recall, precision, F1 score, and Area Under Curve (AUC). For machine learning models, metrics such as RMSE and AUC often provide higher predictive accuracy, especially when dealing with complex data. Statistical methods, on the other hand, emphasize model interpretability, using metrics like Akaike Information Criterion (AIC) and McFadden's R^2 for assessing model fit and significance. The integration of machine learning techniques has significantly enhanced the precision of pedestrian crash predictions, enabling more targeted interventions to improve pedestrian safety. Despite these advancements, both statistical and machine learning models have strengths and limitations. Statistical methods are valuable for understanding causal relationships and smaller datasets, while machine learning excels in handling large, complex datasets. Future research should focus on integrating the strengths of both approaches, improving the incorporation of pedestrian behavior factors, and utilizing real-time data to enhance model performance.

Conflict of Interest

The authors acknowledge the support provided by the National Transportation Planning and Research Centre (NATPAC) during this study. The authors also declare that this manuscript has not been published previously and is not under consideration for publication elsewhere. Furthermore, all authors have read, reviewed, and approved the final version of the manuscript submitted to the journal, and there are no conflicts of interest or ethical concerns associated with this submission.

REFERENCES

Alireza Toran Pour, Moridpour, S., Tay, R., & Abbas Rajabifard. (2016). Modelling pedestrian crash severity at mid-blocks. Transportmetrica, 13(3), 273–297.

Amoh-Gyimah, R., Saberi, M., & Sarvi, M. (2016). Macroscopic modeling of pedestrian and bicycle crashes: A cross-comparison of estimation methods. Accident Analysis & Prevention, 93, 147–159.

Backett, E. M., & Johnston, A. M. (1997). Social patterns of road accidents to children: some characteristics of vulnerable families. Injury Prevention, 3(1), 57–62.

Chakraborty, A., Mukherjee, D., & Mitra, S. (2019). Development of pedestrian crash prediction model for a developing country using artificial neural network. International Journal of Injury Control and Safety Promotion, 26(3), 283–293.

Das, S., Le, M., & Dai, B. (2020). Application of machine learning tools in classifying pedestrian crash types: A case study. Transportation Safety and Environment, 2(2), 106–119.

Davis., Scott, E, Robertson, Douglas, H , King, Ellis, L. (1989). Pedestrian/vehicle conflicts: an accident prediction model. Transportation Research Record 1210.

Elalouf, A., Birfir, S., & Rosenbloom, T. (2023). Developing machine-learning-based models to diminish the severity of injuries sustained by pedestrians in road traffic incidents. Heliyon, 9(11).

Guo, Q., Xu, P., Pei, X., Wong, S. C., & Yao, D. (2017). The effect of road network patterns on pedestrian safety: A zone-based Bayesian spatial modeling approach. Accident Analysis & Prevention, 99, 114–124.

Haleem, K., Alluri, P., & Gan, A. (2015). Analyzing pedestrian crash injury severity at signalized and non-signalized locations. Accident Analysis & Prevention, 81, 14–23.

Hossain, M. M., Zhou, H., Sun, X., Hossain, A., & Das, S. (2024). Crashes involving distracted pedestrians: Identifying risk factors and their relationships to pedestrian severity levels and distraction modes. Accident Analysis & Prevention, 194, 107–359.

Islam Khan, Md. M., & Rahman, Md. H. (2016). A prediction model for pedestrian fatalities based on explanatory factors. IOSR Journal of Mechanical and Civil Engineering, 13(05), 20–24.

Kraidi, R., &Evdorides, H. (2020). Pedestrian safety models for urban environments with high roadside activities. Safety Science, 130, 104–847.

Meocci, M., Branzi, V., Martini, G., Arrighi, R., & Petrizzo, I. (2021). A Predictive Pedestrian Crash Model Based on Artificial Intelligence Techniques. Applied Sciences, 11(23).

Mostafizur, M., Komol, R., Hasanid, M., Elhenawy, M., Yasmin, S., Masoud, M., & Rakotonirainy, A. (2021). Crash severity analysis of vulnerable road users using machine learning.

Mukherjee, D., & Mitra, S. (2020a). A comprehensive study on identification of risk factors for fatal pedestrian crashes at urban intersections in a developing country. Asian Transport Studies, 6.

Mukherjee, D., & Mitra, S. (2020b). Pedestrian safety analysis of urban intersections in Kolkata, India using a combined proactive and reactive approach. Journal of Transportation Safety & Security, 14(5), 754–795.

Padgaonkar, A. J., Krieger, K. W., & King, A. I. (1977). A Three-Dimensional Mathematical Simulation of Pedestrian-Vehicle Impact with Experimental Verification. Journal of Biomechanical Engineering, 99(2), 116–123.

Rahman, M. S., Abdel-Aty, M., Hasan, S., & Cai, Q. (2019). Applying machine learning approaches to analyze the vulnerable road-users' crashes at statewide traffic analysis zones. Journal of Safety Research, 70, 275–288.

Rankavat, S., & Gupta, V. (2023). Risk perceptions of pedestrians for traffic and road features. International Journal of Injury Control and Safety Promotion, 30(3), 410–418.

Rankavat, S., & Tiwari, G. (2016). Pedestrians perceptions for utilization of pedestrian facilities – Delhi, India. Transportation Research Part F: Traffic Psychology and Behaviour, 42, 495–499.

Rella Riccardi, M., Mauriello, F., Sarkar, S., Galante, F., Scarano, A., & Montella, A. (2022). Parametric and Non-Parametric Analyses for Pedestrian Crash Severity Prediction in Great Britain. Sustainability, 14(6), 31–88.

Shankar, V. N., Ulfarsson, G. F., Pendyala, R. M., & Nebergall, M. B. (2003). Modeling crashes involving pedestrians and motorized traffic. Safety Science, 41(7), 627–640.

Sze, N. N., & Wong, S. C. (2007). Diagnostic analysis of the logistic model for pedestrian injury severity in traffic crashes. Accident Analysis & Prevention, 39(6), 1267–1278.

Tao, W., Aghaabbasi, M., Ali, M., Almaliki, A. H., Zainol, R., Almaliki, A. A., & Hussein, E. E. (2022). An Advanced Machine Learning Approach to Predicting Pedestrian Fatality Caused by Road Crashes: A Step toward Sustainable Pedestrian Safety. Sustainability, 14(4), 24-36.

Telima, M., El Esawey, M., El-Basyouny, K., & Osama, A. (2023). The use of crowdsourcing data for analyzing pedestrian safety in urban areas. Ain Shams Engineering Journal, 14(6), 102–140.

Tiwari, G. (2020). International Journal of Injury Control and Safety Promotion Progress in pedestrian safety research Progress in pedestrian safety research.

Ul Arifeen, S., Ali, M., &Macioszek, E. (2023). Analysis of vehicle pedestrian crash severity using advanced machine learning techniques. Archives of Transport, 68(4), 91–116.

Van Houten, R. (1988). The effects of advance stop lines and sign prompts on pedestrian safety in a crosswalk on a multilane highway. Journal of Applied Behavior Analysis, 21(3), 245–251.

WHO. 2023. Global status report on road safety 2023.

Yang, L., Aghaabbasi, M., Ali, M., Jan, A., Bouallegue, B., Javed, M. F., & Salem, N. M. (2022). Comparative Analysis of the Optimized KNN, SVM, and Ensemble DT Models Using Bayesian Optimization for Predicting Pedestrian Fatalities: An Advance towards Realizing the Sustainable Safety of Pedestrians. Sustainability, 14(17).

Zhai, X., Huang, H., Sze, N. N., Song, Z., & Hon, K. K. (2019). Diagnostic analysis of the effects of weather condition on pedestrian crash severity. Accident Analysis & Prevention, 122, 318–324.