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*Review Article*

# Examining Car Accident Prediction Techniques and Road Traffic Congestion: A Comparative Analysis of Road Safety and Prevention of World Challenges in Low-Income and High-Income Countries

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Road accidents are a significant negative outcome of transportation systems, causing injuries, fatalities, traffic congestion, and economic losses. As cities expand and the number of vehicles on the road increases, traffic accidents (TAs) have become a significant problem. Studies have shown that urban development plays a more significant role in transportation safety than previously thought. Low-income countries have higher fatality rates than high-income countries, according to the Permanent International Association of Road Congress (PIARC) and the World Health Organization (WHO). Predicting and preventing the occurrence of accidents and congestion is necessary worldwide, especially in developing countries where fatality rates are higher. The objective of this study is to examine and make a comparative analysis in low-income and high-income countries of the existing literature on the global challenge of car accidents and use its prediction techniques to enhance road safety and reduce traffic congestion. The study evaluates various approaches such as logistic regression, decision tree, random forest, deep neural network, support vector machine, random forest, K-nearest neighbors, Naïve Bayes, empirical Bayes, geospatial analysis methods, and UIMA, NSGA-II, and MOPS algorithms. The research identifies current challenges, prevention ideas, and future directions for preventing accidents and congestion on the road network. Integrating GIS-based spatial statistical methods and temporal data and utilizing advanced optimization algorithms and machine learning methods can result in accurate prediction models that can help identify accident hotspots and reduce congestions and enhance traffic safety and mitigate their occurrence. Effectively preventing urban traffic congestion requires the integration of spatial data into precise accident prediction models. By employing spatial analysis, road safety planning can be enhanced, high-risk areas can be identified, interventions can be evaluated, and resources can be optimally allocated to facilitate effective road safety measures and decision-making, especially in settings with limited resources. Therefore, it is crucial to consider ML and spatial analysis techniques and advanced optimization algorithms to enhance traffic flow control, in road safety research and transport planning efforts.

## 1. Introduction

The objective of the transportation system is to support the safe and efficient movement of people and goods. A significant unexpected outcome of transportation systems is road accidents with injuries and loss of life and economy. According to the World Health Organization, 1.35 million fatalities occur on the world's roads annually [1]. In addition, traffic collisions contribute significantly to traffic congestion, which is a serious issue affecting the society as a whole [2]. Road traffic accidents are increasingly recognized as the major problem, particularly in developing countries like Ethiopia. The global status on road safety in 2018 indicated a continued rise in worldwide road traffic deaths, reaching 1.35 million per year in 2016, making it the leading cause of death for individuals aged 5–29. Globally, pedestrian and cyclist fatalities constitute a significant portion, amounting to 26% of all deaths, while users of motorized two- and three-wheelers account for an additional 28%. Developing countries bear a disproportionate burden of road traffic injuries. In the African subregion, pedestrian fatalities account for over half of the total, constituting 55%. Pedestrian fatalities reach alarming levels in Ethiopia, where pedestrians account for 84% of road traffic deaths, and in Cote d'Ivoire, where pedestrians constitute 75% of road traffic fatalities [3]. Notably, Africa experiences the highest proportion of pedestrian and cyclist fatalities, contributing to 44% of all deaths. In the South-East Asia and Western Pacific regions, the majority of fatalities occur among riders of motorized two- and three-wheelers, representing 43% and 36% of the total fatalities, respectively [4]. Despite having less than 60% of the world's motor vehicles, low- and middle-income countries bear the burden of over 90% of all road traffic deaths. Indeed, countries experienced a significant decline in the number of road fatalities during the initial months of 2020, with reported reductions of up to 80% [5]. This decrease can be attributed to the widespread implementation of lockdown measures in numerous countries as a response to the COVID-19 pandemic.

Car accidents and traffic congestion are two primary challenges faced by transportation systems worldwide. While these challenges impact individuals across all income levels, low-income countries encounter unique difficulties that exacerbate these problems. Furthermore, low-income countries exhibit the highest road traffic fatality rates [1, 6]. According to Heydari et al. [7], road traffic injuries represent a significant public health issue in low-income countries, contributing significantly to mortality and disability. There exist also significant gender disparities in road injury patterns, with women facing distinct risks. In the event of a car crash, women have a 47% higher likelihood of sustaining serious injuries compared to men. Furthermore, they are at a five-fold increased risk of experiencing whiplash injuries. By 2030, it is projected that approximately 70% of the global population will reside in urban areas. This rapid urbanization will result in a surge in demand for urban mobility, surpassing the capacity of existing systems. Hence, the Global Plan for the Decade of Action for Road Safety 2021–2030 explicitly aims to reduce road deaths and injuries by at least 50% by 2030 [4].

The term "*accident*" is commonly accepted to describe an incident involving one or more vehicles in a collision, resulting in property damage, injury, or death. The term implies a random event without an apparent cause other than it occurring by chance [8]. Alen and Janice [9] recommended replacing "motor vehicle accident" with "motor vehicle crash" in the clinical and research language used by traumatologists. They argued that "crash" is a more inclusive term that encompasses a wider range of potential causes. Fatal crashes often result from driver intoxication, speeding, distraction, or carelessness and should not be considered as accidents. It is crucial to refrain from labeling such crashes as accidents, as doing so may impede victims' recovery by inhibiting their ability to assign blame and process the emotions associated with their trauma. According to the Highway Safety Manual (HSM), a crash is defined as "a set of events not under human control that leads to injury or property damage due to the collision of at least one motorized vehicle and may involve a collision with another motorized vehicle, a bicyclist, a pedestrian, or an object" [10], highlighting the various incidents that can be categorized as crashes. Road accidents are also referred to as road traffic crashes or collisions in different literatures, as mentioned by Wang [11]. The distinction between a crash and an accident has a significant impact on determining ultimate responsibility for the car accident. When someone is at fault in a car accident, it is typically a preventable collision. The National Safety Council defines a preventable collision as "a collision in which the driver failed to do everything reasonable to avoid it" [12]. This means that the accident could have been avoided if the driver had taken appropriate action. Consequently, someone is accountable for the car crash and can be held liable for it.

Several studies have found that areas with higher population density, increased traffic, and greater urbanization tend to exhibit higher rates of traffic crashes [13]. Conversely, as vehicle numbers rapidly increase and cities expand, traffic incidents have a widespread and an escalating adverse effect on both traffic systems and the quality of social activities. The management of traffic safety assumes a crucial role in intelligent transportation systems (ITSs). Traffic safety management encompasses a broad research domain wherein it is essential to analyze and predict the influence of traffic incidents [14].

Traffic congestion constitutes a major problem in modern urban traffic networks if not well managed. When an excessively large number of cars attempt to utilize a single, constrained transit system, traffic congestion ensues [15]. Its devastating effects can occasionally paralyze a traffic network, consuming significant portions of commuters' productive hours and impeding essential services provided by incidence-intervention vehicles such as emergency and fire-fighting vehicles. Regardless of the cause, traffic congestion's impact is counterproductive and an indicative of an inefficient traffic network. Contributing factors include varying traffic conditions throughout the day and random congestion due to accidents [12].

With the societal development and improved living standards, the rapid increase in the number of vehicles has been accompanied by a rise in frequent traffic accidents. These accidents not only cause casualties and property losses but also disrupt traffic operations, leading to traffic congestion or even traffic breaks [16]. The issue of traffic congestion is a common challenge faced by every country as its infrastructure develops. Consequently, the ability to forecast congestion becomes crucial for authorities in order to devise appropriate plans and undertake necessary actions to prevent its occurrence [17]. The resulting traffic impacts have significant social (fatalities and injuries), economical, and environmental consequences for both developed and developing countries' economies. The growing number of vehicles has transformed traffic, and traffic congestion has become a global issue, causing excessive delays and compromised safety [18]. A decrease in the number of crashes may be associated with the alleviation of traffic congestion in situations involving four or more lanes. However, it is important to acknowledge that having more lanes may lead drivers to feel more relaxed and drive at higher speeds, potentially resulting in more serious accidents [19].

Nonrecurrent congestion, primarily caused by traffic incidents, is widely recognized as a primary factor. Understanding when and where traffic accidents (TAs) occur on a road network is of paramount concern for transportation authorities and safety professionals [20]. Forty to fifty percent of all nonrecurring congestion can be attributed to traffic incidents. Undoubtedly, enhancing transportation safety can alleviate numerous health, financial, and quality-of-life issues faced by travelers [18]. Generally, the main factors affecting congestion on a road include incidents, traffic flow, and road conditions [21].

Traffic congestion not only profoundly impacts economic activities but also has adverse environmental effects, such as increasing noise pollution. Therefore, predicting traffic information in advance is crucial to enable effective and timely countermeasures for mitigation [22]. In addition, predicting crash proneness aids safety studies on urban roads, enabling the implementation of countermeasures and improvements, as well as assisting in the identification and prevention of crashes before they occur.

Traffic accidents are inherently spatial problems, and the machine learning (ML) models should consider various geospatial data sources and their interrelationships. This involves conducting numerous geo-processing operations, which can be computationally intensive. However, the primary goal of the transportation systems is to facilitate the efficient and safe movement of people and goods. Unfortunately, road accidents are a significant adverse outcome, leading to injuries, fatalities, traffic congestion, and economic losses. It is crucial to distinguish between a crash and an accident because the former encompasses a wide range of potential causes, such as speeding, distracted driving, or carelessness, and can be prevented. Effective traffic safety management is essential in preventing and predicting the impact of traffic incidents. Urban traffic networks face significant challenges related to traffic congestion, which results in delays, reduced safety, and environmental harm. Moreover, it can even paralyze traffic networks and impede the movement of emergency and firefighting vehicles. Predicting crash proneness facilitates safety studies on urban roads, enables the identification and prevention of accidents before they occur, and facilitates the implementation of safety measures as well as mitigating traffic congestion.

Therefore, the development of a predictive model becomes necessary to comprehend the road conditions and the distribution of road traffic accidents. Consequently, a predictive model is needed to assist road officials and transport managers in understanding the road conditions and the distribution of road traffic accidents, allowing them to predict and prevent future road traffic accidents and congestion. Ultimately, improving transportation safety can alleviate health, financial, and quality-of-life issues faced by travelers.

In general, there is a persistent and immediate requirement for research that addresses the evolving circumstances in numerous low-income countries (LICs) and enhances the performance of the transportation sector in achieving the United Nations' Sustainable Development Goals (SDGs) [23, 24]. The objective of this article is to offer a comprehensive and current review of the global challenges associated with road traffic accidents and their resulting traffic congestion and road safety prevention mechanisms focusing on the comparison between low-income and high-income countries. As there is a lack of research conducted in low-income countries, we define the scope and focus of the study particularly in Africa despite the fact that they bear the majority of the burden as compared to high-income countries. The aim is to shed light on the significant discrepancies between these two income categories, evaluate the current prediction approaches, suggest the impact prevention mechanisms for car accidents and road network congestion, and identify future research focuses.

To ensure efficient screening, a systematic search of research papers was conducted using various search engines such as Scopus, Google, Google Scholar, Science Direct, and references from relevant articles. All data sources that presented a comprehensive analysis of road traffic accidents in both high-income and low-income countries, including their impact on traffic congestion and preventive mechanisms, were considered eligible for inclusion in the study.

The succeeding sections of the paper are organized as follows: Section 2 provides an overview of the current state of knowledge in road traffic accidents, covering relevant literature, the contextual background, a comparative analysis of such accidents in low-income and high-income countries, methodologies for predicting car accidents, and a discussion on the relationship between road traffic accidents and congestion, including preventive measures. In Section 3, the key findings of the subject, and in Section 4, we present in-depth discussion on the themes and sights derived from the literature review, analysis, and discussion in Sections 2 and 3, identifying gaps for further exploration. Section 5 summarizes our conclusions, including key findings, implications, and recommendations based on the research, along with identifying possible opportunities for future research on accident and congestion prevention.

## 2. State of Knowledge

*2.1. Road Traffic Accidents: A Comparison of Low-Income and High-Income Countries of the Global Challenges.* Detailed analyses of global accident statistics by the United Kingdom (UK) Transport Research Laboratory (TRL) and others indicate that fatality rates per licensed vehicle in developing countries are significantly higher compared to industrialized countries [25]. According to a study by Peden et al. [6] and Naci et al. [3], the distribution of road traffic deaths varies significantly among low-income, middle-income, and high-income countries. The study reveals that 45% of road traffic fatalities in low-income countries occur among pedestrians, while the figures in middle-income and high-income countries are 29% and 18%, respectively. Furthermore, the burden of road traffic injuries on vulnerable road users, such as pedestrians, differs significantly based on income levels. For instance, the study estimates that 227,835 pedestrians die each year in low-income countries, compared to 161,501 in middle-income countries and 22,500 in high-income countries. With economic growth, particularly in low- and middle-income countries, the number of vehicles on the roads has increased, making daily transportation more complex and dangerous [26]. Fatality rates (in relation to vehicle numbers) in the developing world, especially in African countries, can often be 20 to 30 times higher than those in European countries [27]. According to the World Health Organization (WHO) [1], developing countries witness significantly more fatalities from traffic accidents compared to industrialized countries, with much higher economic costs. Car accidents pose a major problem in both low-income and high-income countries, although the causes and impacts of car accidents can vary significantly between these two settings. In low-income countries, factors such as inadequate infrastructure, a lack of safety measures, older vehicles, and inexperienced drivers contribute to a higher rate of accidents [28]. Data unavailability in low- and middle-income countries impedes road safety improvement. Access to data is crucial for scientific research on identifying factors causing high road risk and assessing the effectiveness of interventions [29]. Conversely, in high-income countries, despite the presence of better infrastructure and safety measures, distracted driving and speeding remain significant contributors to accidents [30].

Traffic accidents are one of the most significant issues in our lives. According to the road safety manual published by Permanent International Association of Road Congresses (PIARC) [31], fatality rates (deaths per 10,000 vehicles) are the lowest in developed countries, ranging from 1.1 to 5.0. Conversely, African countries, particularly Ethiopia, Tanzania, and Lesotho have the highest fatality rates, exceeding 100. A notable difference between high-income and low-income countries is that road deaths have decreased by approximately 10% in Western Europe and North America since the mid-1980s, whereas they continue to rise in Africa, Asia/Pacific, and Latin/Central America, and the Caribbean regions. Peden et al. [6] estimated that the annual losses from traffic accidents amount to 518 billion dollars, with low and average-income countries accounting for 65 billion dollars. This indicates that high-income countries spend 2% of their gross national product (GNP) on traffic accidents, while low- and average-income countries allocate 1 to 5.1% of their GNP. In addition, de Andrade et al. [32] demonstrated that road traffic injuries (RTIs) impose a considerable financial burden, particularly on developing economies. Low- and middle-income countries have the highest annual road traffic fatality rates, contributing to 80% of road traffic deaths. Moreover, RTIs are estimated to cost low- and middle-income countries over 100 billion dollars per year, equivalent to 1-2% of their GNP. The increasing number of motor cars plays a major role in the escalating deaths and injuries resulting from traffic accidents in developing nations. As stated by Heydari et al. [7], previous road safety research in low-income countries (LICs) lacks studies on analyzing injury severity levels and understanding the factors that influence them. Such studies, common in developed countries, help decision-makers design effective measures to reduce injuries. Therefore, further research is needed in LICs to address this gap.

The absence or insufficient use of modern traffic management techniques can result in congested and unsafe road networks for road users, with pedestrians being particularly at risk. Unfortunately, little to no effort is made to improve conditions for these vulnerable road users. Recognizing the loss of lives and significant financial costs, scientists are committed to preventing traffic accidents in developing countries [31]. This problem is especially critical in low-income countries (LICs) due to several persistent shortcomings in road safety standards, vehicle safety, and maintenance, as well as in the design and implementation of policies and safe transportation infrastructure. Figure 1 illustrates the relationship between national wealth and road death rates, based on data provided by the WHO [1].

Accurate knowledge of road crashes and their causes can help provide robust motives for the investment of appropriate and effective road safety interventions, which is particularly important in contexts where resources are limited [5]. Data limitations present substantial challenges in road safety analysis, particularly in low-income countries (LICs). These countries commonly face inadequate crash data due to its absence or limited availability, mainly attributed to sample size constraints and a lack of risk factors within the data. As a result, these limitations are more prevalent and frequent in LICs compared to developed nations [7, 23]. The traditional source of such information has been police road traffic crash data, although the accuracy of this data is questionable due to underreporting in all countries. To address this issue, WHO has provided estimates of the number of fatalities in each country using negative binomial modeling based on reported fatalities [1]. According to WHO's estimates, high-income countries have a higher proportion of road fatalities correctly reported, with an average of 88% in high-income countries (HICs) and 77% in middle-income countries (MICs). However, this reporting accuracy is significantly lower in lower-middle-income countries (LMICs) at 52% and low-income countries (LICs) at 17% of road fatalities correctly reported.

The mortality rate is useful for comparing road safety across countries [5]. In general, developing countries experience much higher fatality rates per licensed vehicle compared to industrialized countries. The combination of economic growth and increased vehicle use contributes to the increased risk in transportation. Among developing countries, particularly in Africa, the fatality rates are considerably higher compared to European countries, as shown in Figure 2. The annual economic costs associated with traffic accidents are estimated to be in the billions of dollars, with low- and middle-income countries bearing the majority of this burden. However, it is important to note that the accuracy of police road traffic crash data remains questionable, with underreporting being a prevalent issue in all countries [1]. Therefore, obtaining accurate knowledge of road crashes and their causes is crucial for implementing

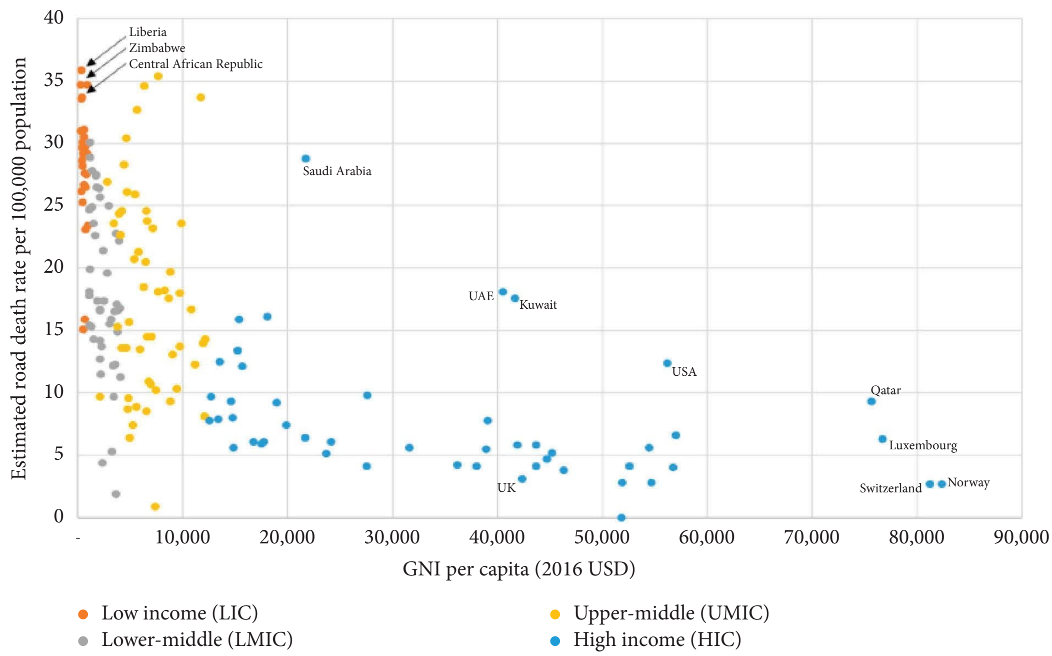


Figure 1: Comparing road traffic death rates with national wealth (source: [1]).

effective road safety interventions, especially in context where resources are limited.

In general, Table 1 compares traffic accident impacts in low-income and high-income countries. It reveals that pedestrian fatalities are higher in low-income countries (Ethiopia: 84%, Cote d'Ivoire: 75%) compared to high-income countries (18%). Road traffic fatality rates are also significantly higher in low-income countries, and the burden of road traffic injuries primarily affects low- and middle-income countries. Furthermore, higher-income countries demonstrate better reporting accuracy for road fatalities. In summary, Table 1 highlights the disparities in traffic accident impacts between low-income and high-income countries.

*2.2. Methods of Car Accident Prediction.* If drivers and pedestrians are aware of the locations and timing of collision hotspots on the roads, they are more likely to avoid them or adopt more defensive strategies when approaching [2]. Zhu [33] conducted extensive research on traffic safety warning technologies and methods using macro-forecast and microforecast approaches. Macro-forecasting involves utilizing macrodata such as the number of traffic accidents, death tolls, and the number of motor vehicles owned to forecast traffic safety warnings. To achieve this, Zhu introduced an integrated forecast method that combines time series and regression forecast methods to provide macro-traffic safety warnings. Lu et al. [34] studied the relationships between the traffic accident and factors such as road type, vehicle type, driver state, weather, and date using statistical analysis and logistic regression analysis. Based on recently collected 400 sets of accident data from 10 major roads in Beijing, they established a prediction model for accident hotspots. The prediction model was validated and showed an approximate prediction accuracy of 86%. In their research, Abou-Amouna et al. [35] aimed to identify and analyze the factors with a significant impact on road accidents in Qatar and predict the total number of road accidents in 2022. They discussed alternative methods and found that the most applicable ones, based on previous research studies that aligned with the existing case in Qatar, were the multiple linear regression model (MLR) and artificial neutral network (ANN) models. After analyzing these methods and comparing their findings, they concluded that using MLR projected 355,226 accidents in 2022, while ANN projected 216,264 accidents. Therefore, they concluded that MLR provided better results than ANN due to the latter's inability to handle data with large range variations. Oyetunji et al. [36] developed a road traffic accident predictive model using the naive Bayes' model to forecast road traffic accidents in Nigeria, aiming to prevent or reduce their occurrence. The system demonstrated reliability with 89.83% accuracy, using selected dependent variables such as road condition, road dimension, human factors, and vehicular factors. Traffic accidents resulting in significant damage occur frequently. Predicting future accidents in advance can be an effective solution, providing drivers with opportunities to avoid dangers or reduce damage by responding quickly. Park et al. [37] build a predictive model using the Hadoop framework to process and analyze large traffic data, along with a sampling method to address data imbalance issues. According to the experiment, the accuracy and true positive rate were 76.35% and 40.83%, respectively, showing close similarity to results from other research. Ghadge et al. [38] employed a machine learning algorithm to predict road bumps using collected data. They utilized an accelerometer sensor for the collection of data and GPS for plotting the location of detected potholes in Google map. Training data were analyzed using the K-means clustering algorithm, and validation was

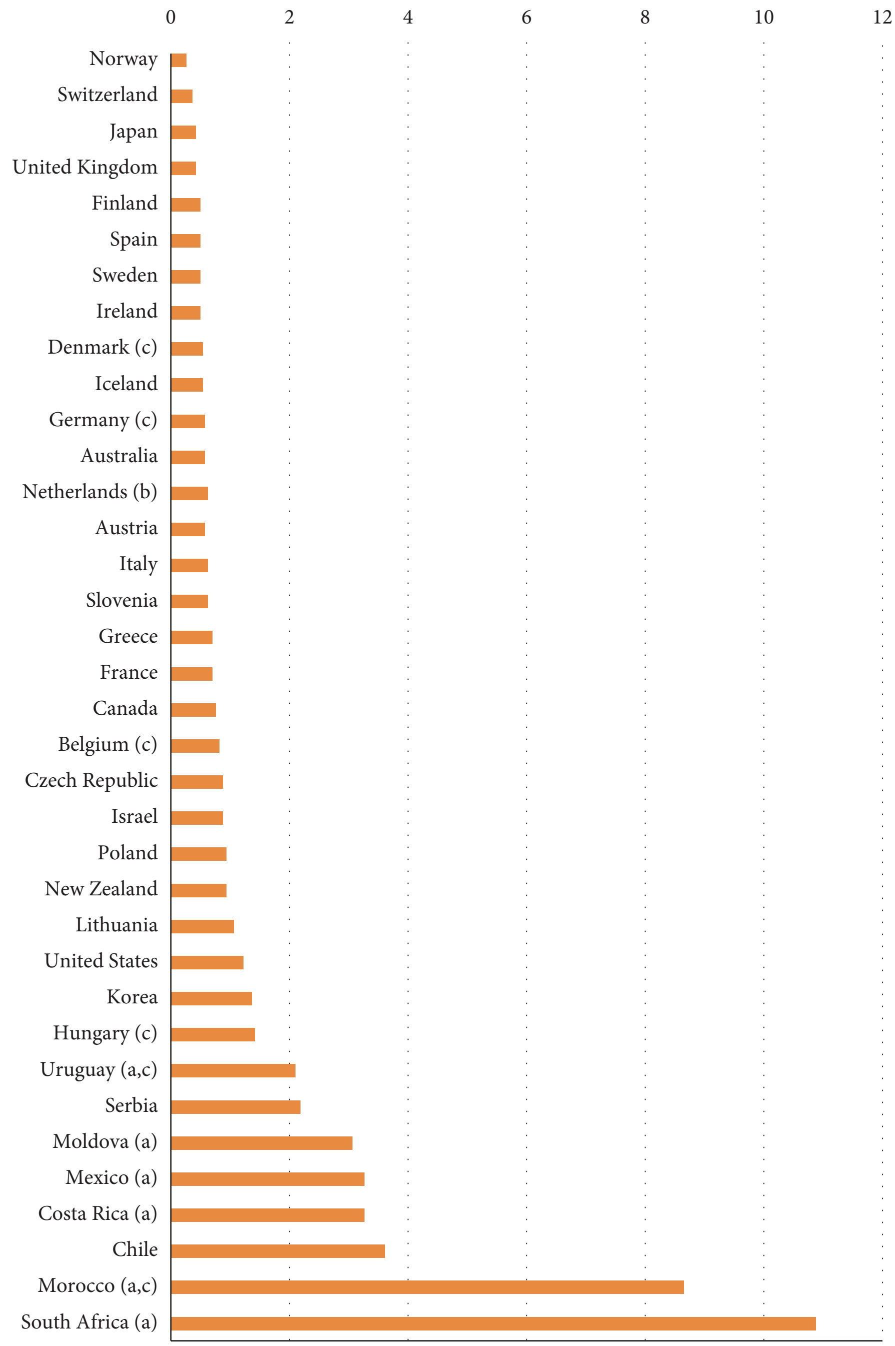


Figure 2: Road fatalities per 10,000 registered vehicles, 2018. Source: ITF road safety annual report 2020 [5].

performed using the random forest classifier. The proposed method yielded the best possible results.

In another study, Yuan et al. [39] utilized big data encompassing motor vehicle crashes in Iowa from 2006 to 2013, along with a detailed road network and various weather attributes at 1-hour interval. They employed four classification models, namely, support vector machine (SVM), decision tree, random forest, and deep neural network (DNN). To address the issue of imbalanced classes, they implemented an informative negative sampling approach. In addition, they tackled the challenge of spatial heterogeneity challenge by incorporating SpatialGraph features through Eigen analysis of the road network. The results demonstrated that employing informative sampling and integrating SpatialGraph features significantly enhanced the performance of all models with random forest and DNN generally outperforming the other models. The use of machine learning algorithms for predicting car accidents has shown promising outcomes in both low-income and high-income countries. For instance, a study conducted in India employed a machine learning model to analyze factors such as road geometry and weather conditions, enabling the prediction of accidents likelihood [40]. Similarly, a study carried out in the United States employed a similar approach

Table 1: Comparison of traffic accident impact statistics in low-income and high-income countries.

| Categories | Low-income countries | High-income countries |
|---|---|---|
| Pedestrian fatalities | 227,835 annually predominant: Ethiopia (84%), Cote d'Ivoire (75%) | 22,500 annually lower: 18% |
| Pedestrian deaths as % of total deaths | 45% | 29% |
| Road traffic fatality rates (per licensed vehicle) | Significantly higher, especially Africa | Lower: 1.1 to 5.0 |
| Cost of road traffic injuries | Low- and middle-income countries: over 100 billion dollars per year (1-2% of GNP) | Much higher due to higher productivity and treatment costs |
| Investment in road safety | Low and average income countries: 1 to 5.1% of GNP | 2% of GNP |
| Underreporting of road fatalities | Lower-middle-income countries: 52% accurately reported | Higher accuracy in high-income countries (88%) |

*Note.* Data sources World Health Organization (WHO), Permanent International Association Of Road Congresses (PIARC), and ITF Road Safety Annual Report 2020.

to predict car accidents using real-time traffic data for accident prediction [41]. Wang et al.'s research [42] utilized floating car trajectory data and two modeling methods: a binary logistic regression model and a support vector machine (SVM) model. These methods were introduced and compared for predicting crash occurrences on urban expressways. Generally, the data collected from floating cars proved effective in predicting crashes on expressways and both models exhibited good performance in predicting crashes. Notably, the SVM model outperformed the binary logistic regression model significantly in crash prediction. Elvik [43] highlighted the use of the empirical Bayes (EB) method and accident prediction models to estimate the expected number of accidents at specific locations, aiding in the identification of hazardous road areas. Strategies can be implemented to enhance the identification of such locations, including the development of a classification system for roadway elements, accident prediction models, and the identification of the upper percentiles of the distribution of EB-estimates of safety.

Moreover, Liu et al. [14] applied the shockwave traffic model, which can be successfully integrated with GIS spatiotemporal analysis, to predict the congestion situation for incidents and for different road hierarchies. Farhan Labib et al. [44] conducted a study figure to identify significant factors that have a clear effect on road accidents and provide beneficial suggestions regarding this issue. The analysis involved the use of four supervised learning techniques: decision tree, K-nearest neighbors (KNN), Naïve Bayes, and AdaBoost. These techniques were used to classify the severity of accidents into fatal, grievous, simple injury, and motor collision between these four categories. AdaBoost demonstrated the best performance in this classification task. Formosa et al. [45] developed a real-time traffic conflict detection method using deep learning (DL) methodology, achieving an accuracy rate of 94%. In addition, Brühwiler et al. [46] highlighted the importance of adding geographical context features to enhance prediction performance and improve model performance for all machine learning (ML) models. Liu et al. [47] utilized machine learning algorithms, such as random forest and logistic regression, to build a prediction model for traffic accidents in a multiethnic plateau mountain area, achieving an accuracy rate of over 80%. In the study by Atumo et al. [19], ML demonstrated unique benefits that conventional approaches cannot replicate. By analyzing crash data, ML enables the identification of trends and patterns that are difficult to detect using other methods. The random forest method, in particular, facilitated the ranking of predictor variables and the identification of sites, allowing for proactive consideration of precursor variables and surpasses traditional hot spot modeling techniques. However, in a study by Sun et al. [48], a deep learning model called long short-term memory (LSTM) was employed to extract temporal features from traffic accident data, while XGBoost was used to learn the spatial correlations between different features. The proposed hybrid model, evaluated on a real-world dataset of traffic accidents in China, outperformed traditional machine learning models, such as random forest and support vector machine, as well as single models such as LSTM and XGBoost. In addition, machine learning (ML) algorithms have been utilized to develop predictive models for traffic incidents [49, 50]. In Habibzadeh et al. [20], ML was identified as an effective tool for predicting accident severity and safety solutions on rural roads. The utilization of machine learning algorithms, such as multiple linear regression models, artificial neural networks, random forest, and deep neural networks, has demonstrated promising results in accident prediction [45, 51]. ML algorithms can analyze large amounts of traffic data, including traffic flow, weather conditions, and road geometry, to accurately predict the likelihood of accidents or traffic congestion.

Hence, various studies have suggested that predicting road accidents is a promising approach to mitigating their incidence. These studies have implemented data analysis and machine learning techniques to develop predictive models that analyze crucial factors such as road type, driver state, vehicle type, weather, and date. Furthermore, these studies have demonstrated that integrating spatial and temporal data, as well as applying informative sampling, can significantly enhance the models' performance. Moreover, the implementation of warning technologies that identify collision hotspots can aid drivers and pedestrians in avoiding accidents. In addition, the use of deep learning methodology has shown high accuracy in real-time traffic conflict detection. It is worth noting that these studies emphasize the importance of incorporating spatial data, such as floating car trajectory data and detailed road network data, to build precise accident prediction models. Accurately predicting accidents can help mitigate their occurrence and severity by enabling drivers to steer clear of hazardous areas or take appropriate precautions when approaching them.

*2.3. Traffic Accidents and Road Network Congestion: The Prevention.* Traffic accidents and road network congestion are closely related. Congestion on roads can lead to an increased risk of traffic accidents, while accidents can also contribute to congestion and further traffic delays. In the articles by Zhu et al. [52] and Chen et al. [53], it is noted that traffic accidents are one of the main factors causing road network congestion on urban roads and increasing travel time. The concepts of "predict and provide" and "predict and prevent," introduced by Goodwin [54], are associated with the challenges of urban traffic management. The idea is to predict the amount of traffic and then construct sufficient road capacity to accommodate it, aiming to prevent traffic accidents and congestion on the road network. However, merely increasing roadway capacity may not be enough, as it often generates traffic. Traffic congestion maintains equilibrium by reaching a threshold where delays discourage additional peak-period vehicle trips. Expanding congested roads attracts latent demand, resulting in generated traffic from other routes, times, and modes. This additional peak-period vehicle traffic is influenced by roadway improvements that reduce user costs. Ignoring these factors can distort planning decisions, highlighting the importance of considering them in order to effectively address traffic congestion. Therefore, alternative strategies for reducing congestion prove to be more effective and cost-efficient [40]. Identifying high-crash-density road segments, commonly referred to as hotspots, is essential for enhancing road safety and promoting a secure driving environment. By pinpointing these areas, targeted interventions can be implemented to mitigate the risk and improve overall safety on the road network [55]. There is substantial evidence suggesting that when traffic congestion occurs downstream, the number of crashes happening upstream tends to increase. This phenomenon is particularly expected on high-speed roads since encountering sudden traffic stops could result in rear-end collisions [56].

The term "traffic management" is used to describe the general process of adjusting or adapting the use of existing road systems to improve traffic operations without resorting to major new construction. Traffic management usually aims to improve traffic flows, reduce accidents, improve environments, or provide better access for people and goods [27]. Hence, the absence or insufficient use of modern traffic management techniques can result in congested and unsafe road networks for road users. A study was conducted using a before-and-after methodology, comparing the number of collisions after the installation of the system. The results showed a significant reduction in the number of collisions after the system was installed, suggesting that the system is effective in reducing collision risks on local roads [57]. Auclair [58] highlighted the negative impact of road traffic congestion, rating it at 54.5% in major cities worldwide. However, road traffic congestion is expected to worsen by 61.3% compared to public transportation and air pollution in the near future. The study by Mazloh et al. [59], examined the factors that contribute to traffic congestion, including population growth, insufficient infrastructure, traffic management challenges, and ineffective transportation policies. They concluded that a comprehensive approach involving integrated planning, policy coordination, and the utilization of advanced technologies is necessary to optimize traffic flow and alleviate congestion in urban areas.

The study by Jiang et al. [60] built a dynamic traffic incident management system (DTIMS) for the purposes of detecting, confirming, and resolving incidents, distributing incident information, managing on-site traffic, and recording and analyzing incidents. As a major component of DTIMS, the traffic incident information management system (TIIMS) provides real-time traffic incident information to traffic managers and participants, aiding them in making quick and accurate decisions. This can be done by applying and utilizing geographic information system for transportation (GIS-T), this system reduces the danger and delays caused by the incidents. The traffic information platform serves as the foundation for TIIMS, providing traffic incident information and geographic data [61].

Urbanism has a significant impact on traffic safety, as summarized by Tărîţă Cîmpeanu and Burlacu [62]. Therefore, urbanism and spatial planning are tools that can achieve synergy among requirements, possibilities, and road functioning, ultimately achieving sustainable development in a given area. Through proper planning, we can ensure efficient public transport, which has a positive impact on traffic, mobility, energy savings, and the environment.

Road traffic crashes and injuries pose major health, economic, and developmental challenges for many African countries. Despite accounting for only 4% of the world's motor vehicles, African roads witness over 10% of the total collision fatalities worldwide. Unlike in developed countries, vulnerable road users, particularly Pedestrians, account for more than 40% of the total fatalities on African roads [63]. Road traffic congestion is a global phenomenon that affects cities worldwide. As Pasquale et al. [64] and Fan et al. [2] mentioned, traffic incidents are one of the primary causes of nonrecurrent traffic congestion. Congestion occurs mainly due to capacity reduction caused by lane interruptions of one or more lanes and slowdowns to observe accidents or rescue operations. Wang [11] emphasized that accidents occur when traffic is in motion, implying that no traffic would mean no accidents. Therefore, studying traffic characteristics, such as speed, density, flow, and congestion, is crucial to understanding their impacts on accidents. These traffic characteristics are closely interconnected, and understanding one can provide valuable insights into the other three. Traffic congestion may be beneficial in terms of road safety. This is based on the premise that there would be fewer fatal accidents, and the accidents that occurred would tend to be less severe due to the low average speed when congestion is present. He et al. [65], in this study, described how traffic accidents are some likely outcomes of rapid urban development and increased motorization. These accidents not only result in fatalities and financial losses but also disrupt traffic flow, leading to congestion, and compromising traffic safety. Improving road conditions, implementing effective traffic management strategies, and enhancing driver education and training are effective measures to reduce the number of traffic accidents [14].

The relationship between congestion and safety has been widely acknowledged, but previous research has not adequately quantified this relationship, as investigated by The National Academies Press [66]. Congestion can lead to stalled or slowed traffic, which significantly increases the risk of collisions, especially when high-speed vehicles approach unexpected traffic queues. Clearly, this presents a substantial risk of collision. Thus, treatments that reduce nonrecurrent congestion can help alleviate the frequency of these conditions. As emphasized by Akhtar and Moridpour [17], forecasting congestion also enables authorities to anticipate and proactively address it by making informed plans and implementing necessary actions to prevent its occurrence.

Connected vehicles can share active safety features such as early prediction of traffic conflicts, leading to mitigated risks of traffic collisions [45]. Furthermore, as evaluated by Partheeban and Hemamalini [67], adopting GIS-based transportation system management (GTSM) can identify congestion in the road network and traffic conditions can be improved [68]. Analyzing road conditions and determining the factors influencing road traffic accidents can identify hazardous locations or black spots, serving as a decision support model for road managers and administrations to prevent or reduce future road traffic accidents and congestion on road networks. Aghajani et al. [69] proposed using GIS-based spatial statistical methods to identify and model accident hotspots, aiding decision-makers in implementing appropriate measures to mitigate road accidents.

Congestion can arise not only from road traffic accidents but also due to increasing traffic volumes. Traffic congestion maintains equilibrium by reaching a threshold where delays discourage additional peak-period vehicle trips. Expanding congested roads attracts latent demand, resulting in the generated traffic from other routes, times, and modes. This additional peak-period vehicle traffic is influenced by roadway improvements that reduce user costs. Ignoring these factors can distort planning decisions, highlighting the importance of considering them in order to effectively address traffic congestion [70]. Zhu et al. [52] propose an intelligent approach to predict and prevent urban traffic congestion through real-time data analysis, considering factors such as traffic flow, road network topology, and weather conditions. This approach aims to proactively manage traffic to prevent accidents and reduce congestion. Intelligent transportation systems (ITS) play a crucial role in managing traffic safety and reducing accidents and congestion ([41, 71]). Adaptive traffic signal control, electronic toll collection, and intelligent speed adaptation are ITS technologies that improve traffic flow and reduce accident likelihood. ITS also facilitates the sharing of real-time traffic data with drivers, enabling them to make informed decisions and avoid congested or accident-prone areas [72]. Li et al. [73] propose an adaptive virtual lane allocation algorithm that dynamically adjusts the number and position of virtual lanes based on real-time traffic information. This method, considering factors like traffic flow, speed, density, and vehicle spatial distribution, demonstrates superior performance in reducing congestion and improving travel time reliability. It holds promises for implementation in urban traffic management systems to improve efficiency and reduce congestion. In another study by Kavoosi et al. [40], the unstructured information management architecture (UIMA) algorithm, originally proposed for solving the spatially constrained berth schedule problem (BSP), has the potential to explore its applicability to road traffic accidents and congestion problems to use it as an effective decision support tool. The UIMA algorithm can assist in determining the most efficient routes for emergency vehicles, helping to minimize response time, ensure effective resource utilization, and potentially save lives. Advanced optimization algorithms offer potential solutions for accident prediction and roadway congestion problems by leveraging their capabilities in optimizing complex systems and decision-making processes. These algorithms can enhance prediction accuracy and assist in developing proactive measures to prevent accidents and alleviate congestion [51]. For instance, the UIMA algorithm can be utilized to optimize traffic management strategies and alleviate road congestion. Ambulance routing algorithms, such as NSGA-II (nondominated sorting genetic algorithm II) and MOPSO (multiobjective particle swarm optimization), can also be adapted and applied to address road traffic accidents and congestion problems prevention in ways like emergency response planning, dynamic traffic management, resource optimization and traffic flow control [74].

In summary, as indicated in Table 2 , traffic accidents and road network congestion are closely linked. Managing one can alleviate the impact of the other. The real-time data analysis and predictive models empower traffic management systems to prevent accidents and reduce congestion on urban roads. Traffic management seeks to improve traffic flows, reduce accidents, improve environments, and provide better access for people and goods. Neglecting or underutilizing modern traffic management techniques can result in congested and unsafe road networks. Urbanism significantly affects traffic safety, making urbanism and spatial planning essential tools for achieving sustainable development. Low-income countries, especially in Africa, face significant challenges regarding road traffic crashes and injuries that constitute major health, economic, and development challenges. Traffic incidents play a major role in nonrecurrent traffic congestion, and reducing congestion through design treatments or intelligent transportation system improvements positively affects safety. Planning and funding for safety-related changes not only save lives and prevent accidents but also alleviate traffic congestion [56]. GIS and transportation research have long been intertwined [47]. Adopting GIS-based transportation system management enables the identification of congestion and improvement of traffic conditions in the road network solving the urban transportation problem [75]. The UIMA algorithm, initially designed for the Berth Schedule Problem, holds potential as a decision support tool for road traffic accidents and congestion. It optimizes emergency vehicle routing, reduces response time, improves resource utilization, aids in traffic management, and mitigates congestion. Adapted ambulance routing algorithms such as NSGA-II and MOPSO enhance traffic flow control through prevention measures, including emergency response planning, dynamic traffic management, and resource optimization.

## 3. Key Findings

Table 3 summarizes the key findings on the connections between traffic accidents, road congestion, and prevention strategies. Developing countries, especially in Africa, have significantly higher fatality rates per licensed vehicle compared to industrialized nations. Low- and middle-income countries bear the greatest burden of road traffic injuries, with pedestrians being the most vulnerable users. Traffic accidents incur substantial economic costs, particularly affecting the low- and middle-income countries. Understanding the causes of road crashes is crucial for implementing effective road safety interventions, especially in resource-limited settings. Machine learning algorithms and various methods have been used to predict car accidents by considering factors like road type, weather conditions, and driver behavior. Accurate accident prediction can help reduce their frequency and severity. Traffic accidents and road congestion are closely intertwined, as congestion

Table 2: The relationship between road traffic accidents, traffic congestion, and prevention options.

| Road traffic accidents | Traffic congestion | Prevention options |
|---|---|---|
| (i) Main factors causing road network congestion on urban roads | (i) Can lead to an increased risk of accidents | (1) Modern traffic management techniques:<br>(i) improve traffic flows, reduce accidents, improve environments, and provide better access for people and goods<br>(2) Intelligent transportation systems (ITS):<br>(i) adaptive traffic signal control, electronic toll collection, and intelligent speed adaptation<br>(3) Real-time data analysis and predictive models<br>(i) Predict and prevent urban traffic congestion and manage traffic to reduce accidents and congestion<br>(4) Adaptive virtual lane allocation algorithm:<br>(i) Dynamically adjust virtual lanes based on real-time traffic information to reduce congestion and improve travel time reliability<br>(5) Machine learning algorithms such as multiple linear regression models, artificial neural networks, random forest, and deep neural networks, has demonstrated promising results to prevent accidents and alleviate congestion<br>(6) The UIMA algorithm and NSGA-II and MOPSO algorithms<br>(i) Optimizes emergency vehicle routing, reduces response time, improves resource utilization, aids in traffic management, and mitigates congestion<br>(7) GIS-based transportation system management:<br>(i) Identify and improve traffic conditions using GIS and spatial statistical methods<br>(8) Planning and funding for safety-related changes:<br>(i) Improve road conditions, traffic management, and driver education to reduce accidents and ease traffic |
| | (ii) Can be caused by traffic incidents, capacity reduction, and slowdowns due to accidents or rescue operations | |
| | (iii) Traffic volumes rise and discouraging additional peak-period vehicle trips | |
| (ii) Increase the risk of accidents | | |
| | (iv) Generated traffic: more peak-period vehicle traffic on a specific road due to expanded congested highways | |

Table 3: Key findings.

| Key findings | Reference | Summary |
|---|---|---|
| Developing countries have higher fatality rates per licensed vehicle compared to industrialized countries, with significantly higher rates in African countries | Peden et al. [6]; Naci et al. [3]; World Health Organization [1]; ITF [5] | Fatality rates in developing countries, especially in Africa, are much higher than in industrialized countries. The burden of road traffic injuries is greater in low-income countries compared to high-income countries |
| Low-income and middle-income countries bear the majority of the economic costs associated with traffic accidents, with costs estimated to be in the billions of dollars annually | Peden et al. [6]; de Andrade et al. [32] | The annual economic costs of traffic accidents are significantly higher in low-income countries compared to high-income countries. These costs constitute a substantial portion of their gross national product (GNP) |
| Accuracy of police road traffic crash data is questionable, with underreporting being prevalent in all countries | World Health Organization [1] | The accuracy of police-reported road traffic crash data is low, with underreporting being a common issue even though the degree is higher in low-income countries |
| Accurate knowledge of road crashes and their causes is crucial for implementing effective road safety interventions, especially in resource-limited contexts | Permanent International Association of Road Congress (PIARC) [31]; World Health Organization [1]; ITF [5] | Obtaining accurate knowledge of road crashes and their causes is important for implementing effective road safety interventions, particularly in contexts where resources are limited. Police data may not provide accurate information and estimates from organizations like WHO can help fill this gap |
| Predictive models using machine learning algorithms show promise in predicting car accidents and can aid in prevention efforts | Zhu [33]; Lu et al. [34]; Abou-Amouna et al. [35]; Abou-Amouna [51]; Oyetunji et al. [36]; Park et al. [37]; Ghadge et al. [38]; Yuan et al. [39]; Wang [42]; Elvik [43]; Liu et al. [14]; Farhan Labib et al. [44]; Formosa et al. [45]; Brühwiler et al. [46]; Liu et al. [47]; Atumo et al. [19]; Sun et al. [48]; Habibzadeh et al. [20] | Machine learning algorithms have been used to develop predictive models for car accidents, taking into account various factors such as road type, driver state, weather, and more. Spatial and temporal data, as well as informative sampling, can significantly enhance the accuracy of these models. ML algorithms also show potential in predicting congestion and traffic accidents detection |
| Traffic accidents contribute to road network congestion, while congestion increases the risk of accidents | Zhu et al. [52]; Chen et al. [53] | Traffic accidents are a significant factor in causing road network congestion, leading to increased travel time. Congestion can also contribute to an increased number of accidents, particularly rear-end collisions on high-speed roads |
| Traffic management plays a crucial role in improving traffic flows, reducing accidents, and providing better access for people and goods | Permanent International Association of Road Congress (Piarc) [31]; Zhu et al. [52]; Chen et al. [53]; Kavoosi et al. [40]; Rabbani et al. [74] | Advanced optimization algorithms are effective traffic management techniques necessary to improve traffic operations, optimize emergency vehicle routing, reduces response time, reduce accidents, and provide better access for people and goods. Without proper traffic management, roads can become congested and unsafe |

increases accident risks and accidents contribute to congestion. Therefore, effective traffic management algorithmic techniques are essential to improve traffic flow, reduce accidents, and establish safer and less congested road networks free for all users.

## 4. Discussion

The objective of this review article is to examine the worldwide challenges posed by road traffic accidents and traffic congestion particularly a comparison of low-income and high-income countries, as well as to evaluate the existing methodologies utilized in the literature for predicting accidents and addressing traffic safety and congestion prevention. In addition, the study aimed to explore the preventive mechanisms employed to mitigate the impacts of these challenges. Traffic accidents are an inevitable consequence of urban motorization and occur randomly. Nevertheless, effective management and preventive measures can help reduce the number of accidents. Investments in road infrastructure are necessary to enhance road safety, particularly for vulnerable road users, by ensuring appropriate location and design [26]. In developing countries, inefficient road space utilization, weak enforcement, uncontrolled conflicts, and inadequate design of traffic and pedestrian facilities are the primary contributors to traffic congestion and road safety issues [7, 51, 56]. These factors have been identified in various studies as significant challenges to road safety and traffic management [28, 41, 45, 46, 61]. However, the experience of developed countries has shown that traffic management techniques are a cost-effective way to alleviate these problems. The significant negative impact of traffic congestion on road safety can be attributed to the higher speed variance among vehicles within and between lanes, as well as erratic driving behavior. Lower speeds during congested periods can help reduce the overall severity of collisions since collision severity is closely linked to speed, as stated by the Institute of Transportation Engineers [76]. By reducing traffic congestion, it is possible to improve mobility and safety simultaneously [3, 15, 66]. There are policy implications that can optimize traffic flow and improve driving behavior, such as reinforcing electronic warning signs, implementing minimum speed limits, and enforcing "average speed" on specific stretches of the roadway.

A recent study by Sachs et al. [77] demonstrates that both high-income and low-income countries can enhance their road safety systems by improving institutional frameworks, databases, and the application of new technologies and approaches. According to Formosa et al. [45], deep neural network (DNN) models hold potential for use in advanced driver assistance systems (ADAS) to develop proactive safety management strategies for improving traffic safety. However, many systems currently lack the ability to display maps, limiting the scope of traffic safety analysis.

Road traffic accidents and fatalities pose a significant global challenge in both low-income and high-income countries [26, 46, 56, 60]. While low-income countries experience a higher number of fatalities, high-income countries face challenges related to distracted driving and speeding. Insufficient infrastructure, safety measures, outdated vehicles, and inexperienced drivers contribute to the high fatality rates in low-income countries. Vulnerable road users, such as pedestrians, are disproportionately affected in low-income countries. In order to develop and implement effective road safety interventions, accurate knowledge of road crashes and their causes is crucial, particularly in situations with limited funds [5, 7]. However, data collection and reporting often suffer from inaccuracies, especially in LMICs and LICs [34, 41]. To prevent traffic accidents and fatalities, concerted efforts from policymakers, transport planners, and the public are necessary, taking into consideration the specific challenges faced by different countries.

The use of predictive models has attracted interest among researchers in the field of car accident prevention. These models suggest that traffic safety warning technologies can assist drivers and pedestrians in avoiding accident-prone areas. By utilizing macro-forecast and microforecast methods, and these technologies establish prediction models for accident hotspots based on various factors such as road type, vehicle type, driver state, weather, and date. Machine learning algorithms, including multiple linear regression models, artificial neural networks, random forests, and deep neural networks, show promise in accident prediction and congestion mitigation. By considering factors like road type, weather conditions, driver behavior, and historical data, these algorithms enhance prediction accuracy, enabling proactive measures to prevent accidents and alleviate congestion in identified accident-prone areas, optimize resource allocation, and improve overall traffic conditions [19, 45, 51]. Abou-Amouna [51] argues that the multiple linear regression model yields superior results compared to artificial neural networks due to its ability to handle a wide range of varieties. Other studies have employed models such as naive Bayes, Hadoop framework, and classification models, including support vector machine, decision tree, random forest, and deep neural network [50, 51, 53, 56]. The inclusion SpatialGraph features and informative negative sampling can enhance the performance of all models, with random forest and deep neural network performing better than other models [19, 46]. Also, machine learning methods have proven effective in addressing the limitations of spatial studies, thereby enhancing their transferability [13]. The success of predictive models in car accident prevention has been demonstrated in both low-income and high-income countries. For instance, real-time traffic data has been utilized in the United States to predict car accidents, while floating car trajectory data and modeling methods have been employed to predict crashes on urban expressways. Predictive models enable drivers to avoid dangers or minimize damage through swift responses [56].

Geographic Information Systems for Transportation (GIS-T) have gained prominence in researching and managing real-world transportation issues, including urban traffic congestion, particularly in developed countries. However, constraints such as initial prohibitive costs and insufficient expertise have limited the widespread

Table 4: A comparison of methods.

| Methods | Advantages | Disadvantages |
|---|---|---|
| Traditional statistical methods | (i) Established techniques<br>(ii) Interpretable results<br>(iii) Robustness | (i) Assumptions and limitations<br>(ii) Data requirements<br>(iii) Lack of spatial consideration |
| Spatial machine learning methods | (i) Time and resource efficiency<br>(ii) Spatial considerations<br>(iii) Nonlinear relationships<br>(iv) Feature selection | (i) Black box nature<br>(ii) Data requirements and quality<br>(iii) Model complexity and overfitting |
| Advanced optimization algorithms | (i) Scalability<br>(ii) Optimal resource allocation<br>(iii) Real-time adaptability<br>(iv) Scalability | (i) Computational complexity<br>(ii) Model complexity and calibration<br>(iii) Practical implementation challenges |

application of GIS-T in developing countries. Intelligent transportation systems (ITS) can facilitate the sharing of real-time traffic data and provide drivers with real-time information on traffic conditions to help them avoid congested or accident-prone areas [71]. The significance of geospatial information for transport modeling is substantial, yet it is often inadequately considered in many cases, despite its potential to contribute to prevent traffic accidents and reduce road network congestion [61].

A comprehensive approach involving multiple techniques and systems is necessary to prevent traffic accidents and reduce road network congestion [56]. One crucial system is traffic management techniques, which aim to improve traffic flow, reduce accidents, and provide better accessibility for people and goods. The implementation a dynamic traffic incident management system (DTIMS) that utilizes GIS-T and traffic information platforms can deliver real-time traffic incident information to traffic managers and participants, enabling prompt and accurate decision-making and reducing the risks and delays caused by incidents [60].

Proper urbanism and spatial planning can also contribute to preventing traffic accidents and reducing road network congestion by ensuring efficient public transport and achieving synergy among requirements, possibilities, and road functions [2, 16, 32, 34, 38, 46, 50, 56, 65]. Nonrecurrent congestion can be reduced through the application of design treatments or intelligent transportation system (ITS) improvements, leading to improved safety. Active safety features in vehicles can help mitigate the risk of traffic collisions if vehicles are connected and share early predictions of traffic conflicts [56]. The UIMA algorithm, initially developed for the Berth Schedule Problem, shows promise as a decision support tool for road traffic accidents and congestion. It optimizes emergency vehicle routing, reduces response time, improves resource utilization, aids in traffic management, and mitigates congestion [40, 56]. Adapted ambulance routing algorithms like NSGA-II and MOPSO can contribute to prevention through emergency response planning, dynamic traffic management, and resource optimization, enhancing traffic flow control. Finally, algorithms such as UIMA, NSGA-II and MOPS, GIS-based transportation system management (GTSM), and machine learning algorithms can be adopted to identify traffic accidents and congestion in the road network and improve traffic conditions [17, 28, 40, 47, 50, 56, 78]. In general, the advantages, disadvantages, debates, and discussions surrounding the use of traditional statistical methods, spatial machine learning methods, and advanced optimization algorithms in analyzing and preventing car accidents and road network congestion are tabulated in Table 4. Traditional statistical methods offer interpretability and robustness but have limitations in assumptions and spatial considerations [69]. Spatial machine learning methods incorporate spatial relationships but face challenges of interpretability, data requirements, and overfitting [19, 50, 53, 72]. Advanced optimization algorithms optimize resource allocation but have complexities in computation, model calibration, and practical implementation [40, 64, 73]. Discussions revolve around trade-offs, integration of methods, transparency, and prioritization in optimizing objectives [9, 28, 63, 79].

## 5. Conclusions and Future Research Directions

Road accidents and traffic congestion are among the global challenges, particularly in transportation systems. Road accidents result in fatalities, injuries, and economic losses, with developing countries experiencing the highest fatality rates. Traffic congestion is another significant challenge, affecting urban traffic networks and causing delays, reduced safety, and environmental harm. The main aim of this review article was to enhance road safety and address congestion prevention mechanisms in both low-income countries (LICs) and high-income countries (HICs). The article identified and focused on the key challenges faced by these countries, along with preventive measures, in order to define critical areas for future research. The ultimate goal is to improve safety and alleviate road congestion effectively, considering the anticipated rise in traffic. To improve the understanding of traffic accidents and create effective policies to prevent them, further research is necessary. The research studies should investigate the causes and effects of traffic crashes and examine the connection between traffic congestion and accidents. Experts in transportation and officials should prioritize understanding when and where accidents occur on road networks to implement safety improvement measures and prevent congestion. It is important to base techniques for identifying hazardous road locations on a profound and theoretically founded understanding of accident statistics. Geographic Information Systems (GISs) can provide real-time collection, modification, and update of geospatial data and attribute information, making them useful tools for analyzing traffic safety issues related to geographic location.

Machine learning models that consider different geospatial data sources and their relationships with each other are crucial in analyzing traffic accidents and predicting accident occurrences as they are inherently spatial problems. The use of machine learning such as deep neural network (DNN) models and advanced optimization algorithms such as UIMA, NSGA-II, and MOPS algorithms can be employed to develop proactive traffic safety management strategies for improving traffic safety and congestion. In the future, researchers should investigate the application of geospatial and machine learning techniques to analyze and predict the occurrence of accidents on road networks to avoid road traffic accident and congestion.

Research findings suggest that reducing congestion can improve both mobility and safety simultaneously. High-income and low-income countries can improve their road safety systems through improved institutional frameworks, improved databases, road safety engineering, and application of new technologies, approaches, and actions. However, the initial prohibitive costs and inadequate expertise have limited widespread application.

Accurate knowledge of road crashes and their causes is essential for implementing effective road safety interventions, especially where funds are limited. It is crucial to define the problem and identify the factors that contribute to it when establishing measures to improve road traffic safety. This would help us comprehend the behavioral, road-related, and vehicle-related factors that impact the number and severity of injuries in motor vehicle accidents and enable us to identify interventions based on informed decisions. The use of spatial analysis techniques and deep learning methodologies has the potential to enhance the process of road safety planning and decision-making in general in developing countries. This results in high accuracy in real-time traffic conflict detection, and it is essential to incorporate spatial data to build precise accident prediction models. Therefore, predictive models that analyze crucial factors such as road type, driver state, vehicle type, weather, and date can be used to mitigate their incidence.

This review provides valuable insights for anyone interested in the field of road traffic safety and offers a comprehensive overview of the current research on accident prediction and traffic congestion prevention strategies. Evaluating various factors that have been used for accident prediction and traffic congestion analysis and the application of GIS-T in traffic accident and congestion studies are important for future studies. Future research works are better to focus also on the application of cutting-edge technologies such as machine learning algorithms, geospatial techniques, and intelligent transportation systems to improve traffic safety and reduce congestion as traffic is expected to increase in large volumes. By taking a holistic approach that includes several techniques and systems, transportation networks worldwide can address the significant problem of traffic congestion and car accidents by implementing effective road safety interventions. Further research studies prioritize investigating the trade-offs between interpretability and accuracy when using traditional statistical methods versus spatial machine learning models. Integrating different methodologies, such as combining statistical methods with machine learning or optimization algorithms, that offer a more comprehensive framework for accident analysis and prevention has to be assessed too. Furthermore, engaging in discussions on transparency, explainability, data quality in spatial machine learning, and trade-offs in advanced optimization can improve the effectiveness of congestion prevention strategies.

## Data Availability

The data are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.


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